AD-A131 112 EMERGENCY WARNING SYSTEMS PART 2 WARNING SYSTEMS - EVALUATION GUIDELINES(U) PRC VOORHEES MCLEAN VA R C TANCZOS ET AL. JUL 83 PRC-666-PT-2 EMW-C-0680 1/2

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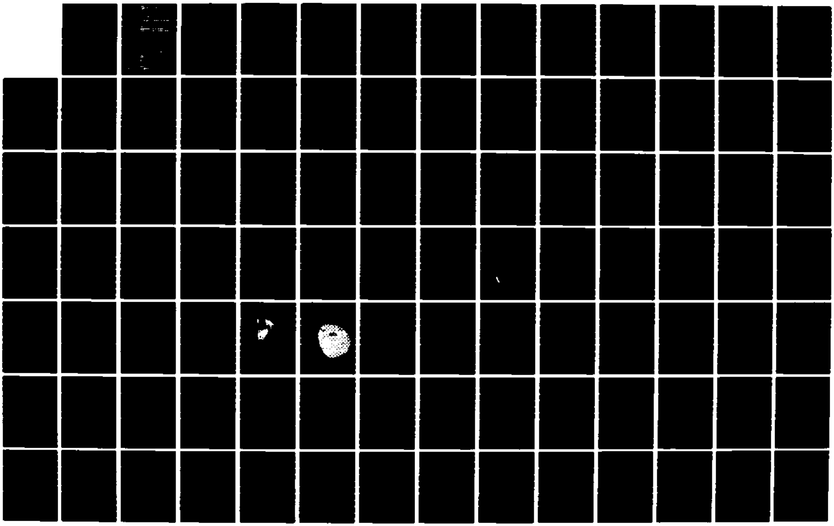

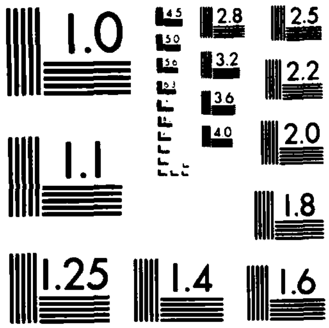
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Prepared For
Federal Emergency Management Agency
Washington, D.C. 20472

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Final Report

Emergency Warning Systems

Part II
WARNING SYSTEMS - EVALUATION GUIDELINES

FEMA Award EMW-C-0680
FEMA Work Unit 2234G

Approved for Public Release:
Distribution Unlimited

July 1983

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER PRC 666	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EMERGENCY WARNING SYSTEMS – PART II WARNING SYSTEMS – EVALUATION GUIDELINES		5. TYPE OF REPORT & PERIOD COVERED Final Report 1982 – 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. C. Tanczos, A. C. Kanen		8. CONTRACT OR GRANT NUMBER(s) FEMA EMW-C-0680
9. PERFORMING ORGANIZATION NAME AND ADDRESS PRC Voorhees 1500 Planning Research Drive McLean, Virginia 22102		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Work Unit 2234G
11. CONTROLLING OFFICE NAME AND ADDRESS FEDERAL EMERGENCY MANAGEMENT AGENCY		12. REPORT DATE July 1983
		13. NUMBER OF PAGES 113
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Background noise
Decibel scale A/C
Emergency Operating Center(EOC)
Emergency Planning Zone(EPZ)
NOAA Radio
Nuclear power plant offsite
Siren coverage
Sound attenuation
Tone alert radio
Warning systems
Washington Area Warning System (WAWAS)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is the result of research performed to establish guidelines for warning systems as they are used for natural disasters, nuclear power plant accidents, or nuclear attacks. The warning systems include both fixed and mobile sirens, tone alert radios, telephone systems, power line devices. Communications systems that control these warning systems are discussed. Test results of several warning systems are included along with a discussion of sound propagation, hearing, and other items that concern the effectiveness of warning systems.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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FEMA Notice: "This report has been reviewed in the Federal Emergency Management Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Emergency Management Agency."

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EXECUTIVE SUMMARY

In the last five decades, warning systems have evolved from simple sirens and door-to-door actions to complex systems. These current systems use radios, telephones, sirens (both fixed and mobile), tone controlled devices, power line modulation techniques and a variety of other methods to act as warning devices. These warning systems also use sophisticated communication methods, providing voice message on a large scale for other actions. To keep step with rapidly evolving technology, and its implications for warning systems especially those now required around nuclear power plants, it has become necessary to define system components, their capabilities, advantages/ disadvantages, and effectiveness.

ACTIVATION

Warning systems, especially those around nuclear power plants, are primarily composed of fixed siren systems. These sirens are often supplemented by mobile sirens, tone activated radios, automatic telephone dialers, or devices connected directly to residential power lines. All of these methods are described in detail in this document, and an overview of the advantages and disadvantages of each system is provided by Table 1.

Generally, the area to be alerted by these types of systems is the 10-mile radius of a nuclear power plant, known as the emergency planning zone, or EPZ. The number of fixed sirens used in a typical 10-mile radius EPZ varies from less than 10 to nearly 100 sirens. The areas not alerted by fixed sirens are informed of emergencies by mobile sirens or tone alert radios.

The operation of a typical warning system is illustrated in Figure 1. For the most common emergencies, a private citizen normally notifies the police or fire department by public telephone. A nuclear power plant emergency, however, would be made known to several agencies either by radio or some form of telephone link that cannot be affected by normal telephone system problems. These are generally dedicated telephone lines from the nuclear facility to a local emergency operations center.

After the proper authority has determined the severity of the emergency, if required, the warning system could be activated. The person in authority depends upon the laws and ordinances in effect in each area. In any case, the emergency control center is generally located at a police, fire, or emergency service organization dispatch and control center. From this control center, a siren system could be activated by radio, telephone lines, or some other direct wire connect means. At the same time, the control center would notify the Emergency Broadcast System (EBS). This is usually a local radio or TV station that broadcasts a message given to them from the control center. The sirens are activated while the EBS is broadcasting details on the emergency. The duration of siren activation and frequency of the EBS message is determined by the nature of the emergency.

WARNING SYSTEM DESIGN

This document deals with many of the technical aspects of warning systems and their operation. As might be expected, fixed siren systems are discussed in great detail, since they probably comprise 90 percent of most warning systems. In designing a warning system, the designer must obtain topographical maps of the area. Such maps are necessary to place sirens where they alert the most people

TABLE 1. MAJOR WARNING SYSTEMS

Method	Advantages	Disadvantages
Outdoor, Fixed Sirens	• Capable of identifiable and sustained signal; electronic sirens have public address capability • Capable of immediate centralized activation by subareas • Responsibility for operation, testing and maintenance is definable • Cost-effective in populated areas	• Sound propagation affected by extreme weather conditions • Public may develop indifference toward siren signal, especially if system activates falsely • Requires periodic maintenance
Indoor Radio Tone Alert/NOAA Radio	• Capable of immediate, centralized activation by subareas • Capable of simultaneous tone alert and voice instruction • Cost-effective in isolated areas	• Testing and maintenance difficult to define • Ineffective for warning persons outdoors
Selective Telephone Dialers	• Same as indoor radio tone alert • Uses existing household telephones	• Not easily adapted for wide-scale application • Difficult to verify testing • Ineffective for warning persons outdoors
Selective Powerline Devices	• Can be used for indoor and outdoor warning	• Not easily adapted for wide-scale application
Mobile Sirens/ Loudspeakers	• Cost-effective in isolated areas • Capable of simultaneous alert and voice instruction	• Difficult to provide widespread coverage within short timeframe • Public perception of warning may be distorted • Susceptible to inclement weather

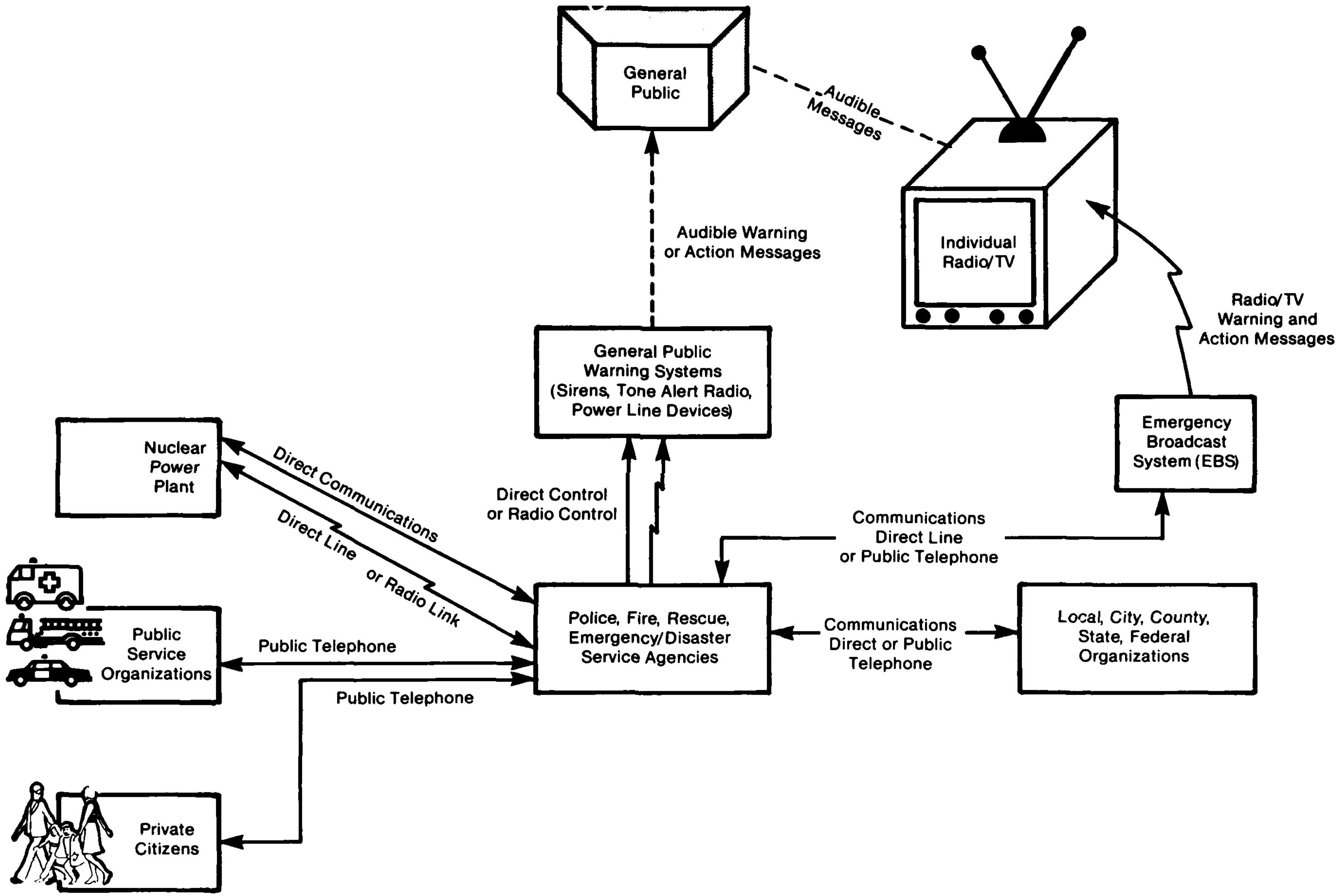


Figure 1. Typical Warning, Communication, and Control System

and sound output is not limited by the surrounding terrain. The topographical maps supplied by the U.S. Geological Survey are recommended, since they give a detailed overview of population concentration by showing all dwellings in the area. These maps also show roads and terrain, with detail such as hills, mountains, rivers, clear or forrested areas, etc. The designer then determines the mix of devices required for the warning system. If a system is devised using all tone alert radios, then the only factor to consider is radio transmitter coverage and signal strength. However, in many cases, a warning system that depends entirely on sound propagation is the most cost-effective. Nevertheless, the following factors should be considered when designing a warning system.

WARNING SYSTEM LIMITATIONS AND RELIABILITY – FIXED SIRENS

When designing a warning system composed primarily of fixed sirens and relying upon sound to alert the general public, there are two major factors that need be considered:

- Compensating for signal weakening with increased distance from source
- Overcoming background noise

Sound Signal Loss Over Distance

In most cases, assume that a siren sound attenuates by 10 dB each time the distance from the source is doubled. Refer to Table 2, which shows this criterion applied to a typical siren with an output power rating of 125 dBC. Note that siren output sound power levels are measured on the dBC scale at 100 feet from the siren at the siren height.

Affects of Background Noise

Siren systems generally use this guide:

The siren sound should be 10 dB greater than the average background noise level to get the attention of someone otherwise occupied.

TABLE 2. SIREN SOUND SIGNAL LOSS CALCULATION FOR DISTANCE DOUBLING OF A 125 dBC RATED SIREN
(10 dB Signal Loss Per Doubling Distance)

Typical Siren Output Rating	Distance From Siren in Feet	Sound Level in dBC
125 dBC	100	125
	200	115
	400	105
	800	95
	1,600	85
	3,200	75
	6,400	65
	12,800	55

Table 2 has been derived as an average guide based upon many factors. The major factors such as topography, weather conditions, atmosphere conditions, etc., that affect sound propagation are discussed in detail in other parts of this document. The most important factor affecting the size of system design, however, is the level of background noise. Note that sound is measured on decible scales that are logarithmic. The dBA scale is used to measure background noise and the dBC scale to measure siren output. When the data of Table 2, and the guideline expressed before it, are considered, the following rule can be stated:

A siren's effective coverage area is doubled for each 5 dB increase at the source. Conversely, the coverage area is halved for a 5 dB loss at the source.

WARNING SYSTEM LIMITATIONS AND RELIABILITY – OTHER DEVICES

With the exception of in-house tone alert radios, all of the warning systems discussed here are installed outside. Consequently, they are exposed to environmental conditions such as rain, snow, heat, cold, etc. These conditions affect the reliability of the equipment, as well as the propagation of sound. The net result is that external environmental conditions can cause system component failures or degraded operations. Extremes of wind, rain, snow, or sleet also limit system operation, usually by attenuating sound or raising the background noise high enough to make warning sound undetectable. In either case, conditions that affect warning system effectiveness must be considered when designing a system. However, not all of the external weather conditions can – or should – be compensated for fully. For example, it would be nearly impossible and highly impractical to design an outdoor warning system to operate 100 percent effectively during a hurricane, since the warning system's function is to alert the population <u>prior</u> to a foreseeable emergency.

<u>System Credibility</u>

Since warning systems are seldom used, system operators may be unfamilar with system operation. This can lead to total system failure or undesirable delays in operator activation. In either case, whether a system fails from operator error or equipment failure, to the general public, the result is the same.

Using data obtained from site visit testing and conversations with several operators, manufacturers, and system managers, the average failure rates for siren systems are as follows:

At least a 5 percent failure rate can be expected for siren warning systems. Failure rates generally average from 5 percent to 20 percent.

System falsing is another factor that can decrease system reliability and effectiveness. This is related to system hardware design. A warning system such as a siren warning system requires immediate action on the part of the listener. If the system is falsely activated too often, the listener will eventually ignore it. The net result is the same as no activation. Probably the major source of the system's false activation is caused by lightning, poor electrical connections, and vandalism. Also, some radio activated systems use a low level of coding on the signals and are falsely activated by spurious radio signals. Of course, there is no perfect solution to preveting falsing. However, it can be minimized as follows:

Pole-mounted sirens should have conduit for housing electrical wires and a good grounding system. Radio-activated systems should use the best available encoder/decoder radios.

INTEGRATION OF MOBILE SIRENS, TONE ALERT RADIO, TELEPHONE AND POWER LINE DEVICES

Almost all siren warning systems integrate a variety of warning devices into the system. In systems covering rural areas where the population density is low, police, fire, and other emergency vehicles often play a major role. Since these mobile units already exist within a system boundary, they are a very cost-effective supplement to a warning system. Mobile sirens are usually well maintained since they, as well as the vehicles they are mounted on, are used routinely. However, severe weather conditions such as heavy snow or ice storms might prolong warning time. Also, the public perception of mobile sirens might not be recognized quickly and could be interpreted simply as the routine passing of an emergency vehicle. However, this situation tends to be lessened since, in warning situations, these vehicles usually drive slowly, using their public address capabilities. In situations where a warning period beyond 10 to 20 minutes is acceptable, mobile siren systems are reasonably effective if they are tested and the public is aware of their purpose.

Tone alert radios are radio receivers that operate in a muted condition. They are activated when a coded signal is transmitted that agrees with the code set into the receiver. Upon receiving this code, a buzzer, light, or some other type of alerting device is activated. Following this, a voice message can be transmitted. Such systems are in use today for alerting volunteer firemen; broadcasting extreme weather conditions (NOAA weather radio); paging employees, etc. The NOAA radio service is used in several instances for nuclear power plant emergencies. Other tone alert radios, operating on local government channels are used to alert key officials and large organizations. These organizations typically include school systems, hospitals, large businesses, and in some cases, private homes.

Automatic telephone calling of private citizens for emergencies is not typically used in large warning systems. Telephone lines that are directly connected and ring automatically are used in limited conditions such as those between emergency organizations and key officials. Although the technology exists to use the telephone system as a warning device for the general public, costs, certain telephone system limitations, and testing verification problems are greater than those for alternative systems. The telephone system, at this time, is best suited to small applications for warning a few hundred locations.

Power line devices are small units similar in size to a power line meter. A special carrier signal is sent on the primary power distribution networks. This carrier is modulated with different addresses and codes to read the power line meter and to perform other switching functions. The same principle is applied to a device attached to the power line next to the meter. This device can contain a small alarm sufficiently loud to alert people inside a home and outside nearby. These devices are currently used on a limited basis. However, their use as an areawide warning system requires careful evaluation on an individual system basis.

RECOMMENDATIONS

As a result of the research performed under this contract and based upon the many tests performed on warning systems and in other related areas; a list of recommendations has been compiled. In this list, the major problem areas concerning warning systems are identified with a recommended course of action. These recommendations can be used to further improve upon existing and new warning systems so that their effective-

ness is increased and their reliability standards are raised to a level consistent with the current state-of-the-art in communication and warning systems.

- **Establish background noise level.** Where it is assumed that the siren system is intended to warn people indoors as well as outdoors, a maximum coverage area should be established for typical siren output sound levels. It is possible that this coverage range would not exceed 6,000 feet for a 125 dBC rated siren. Currently, coverage for the same type siren in equivalent assumed background noise areas varies from 5,000 to 10,000 feet radius.Background noise level readings should be required to establish the effective coverage area of fixed sirens.

- **Agree on a common dB scale.** Most background noise measurements are made using a sound level meter set on the dBA scale. Fixed sirens, however, are rated on the dBC scale. This creates some discrepancy in determining when a siren signal level is 10 dB above the background noise levels, especially for the sirens with output signal frequencies below 550 Hertz. A procedure should be established for measuring background noise using octave or 1/3- octave filters around the frequency ranges of various sirens and an agreement made on a common dB scale for comparing background noise with siren signal acoustic level outputs.

- **Test siren output.** Field tests have shown large differences in measured output power versus manufacturers' published output ratings. Currently available fixed sirens should be sampled for compliance with manufacturers' stated outputs. This should be done on new sirens that are installed in the field. An appropriate sample should be taken from a distance of 100 feet, in a position that is level with the siren height. From this, a qualified product list could be established and siren specifications listed according to independent tests.

- **Train system operators.** System failures or near failures have occasionally resulted from operator error. This by-product of inadequate training can have a detrimental affect on system credibility and effectiveness. Operators of warning systems should be thoroughly trained in the operation of the system. Also, detailed operational procedures should be prominently displayed next to each system control center.

- **Develop mobile siren operational procedures.** When the siren and public address capabilities of emergency vehicles are incorporated into warning systems, their operators, although often familiar with routine use of these capabilities, may not be fully aware of the needs of this type of emergency situation. Guidelines defining recommended emergency vehicle travel speeds and the effective ranges of mobile sirens in specific areas, as well as under various weather conditions, should be developed. Public perception – and possible misunderstanding – of mobile sirens should also be described. For those isolated areas relying heavily upon mobile sirens as the primary warning method, operator training should involve even more detailed guidelines.

- **Strive to eliminate false siren activation.** The more often a system is falsely activated, the less effective the system becomes. The major causes for false siren activation should be identified and steps taken

to help eliminate this problem. The technical expertise of the siren and radio system manufacturers, as well as the advice of manufacturers of other, similar equipment, should be utilized through organized and in-depth interviews. This would allow for the formulation of specific techniques to eliminate most of the problem of false activation.

- **Investigate use of paging systems.** Recent regulatory changes by the Federal Communications Commission (FCC) have affected the use of tone alert radios and, more specifically, the uses of paging systems. As a consequence, these units are being designed to provide greater capabilities at reduced costs. Such systems may have wider application for emergency warning scenarios and should be studied. Also, with these new devices it is now possible to add two-way communications capability. These new technological developments should be investigated.

- **Research siren verification capability.** Most siren warning systems have no immediate method of determining whether all sirens have been successfully activated. Verification of siren activation is usually known only after the emergency has passed. Some recent work has been done to verify systems operation by radio links back to central control from each siren. This capability should be identified and considered for future systems.

1. INTRODUCTION

This document has been prepared to serve as a guideline for FEMA and NRC on the design and evaluation of warning systems. This research effort has involved a careful study of many different types of warning systems and included field tests at five nuclear power plant sites. In addition, tests were also performed on the Washington Area Warning System, and 10 other systems were analyzed from various design documents. This effort has also included discussions with all of the major U.S. manufacturers of fixed siren equipment, as well as with several manufacturers of radio control equipment, telephone dialer/switching equipment, and power line current carrier equipment. In-depth studies were made concerning those aspects of noise, sound propagation, construction methods, and other factors that affect sound propagation.

Extensive studies were also made concerning background noise levels, their measurement, and the different decibel scales used in these measurements. The effects of topographical conditions were also investigated. All of these data were then combined to show the major effects that each area has upon siren system effectiveness. The attached bibliography indicates the extensive use of other documents to compare different test results of many siren manufacturers' equipment. In addition, numerous interviews were held with those people who control, operate, and maintain the warning systems discussed.

Accordingly, this document covers equipment power requirements that can greatly affect siren output power levels and, therefore, influence system effectiveness. Other factors that affect system reliability are discussed from an operational as well as a design perspective. Finally, typical system cost figures are provided for systems and individual equipment pieces. A companion document, "Emergency Warning Systems, Part 1" contains data on other types of systems and also includes details on nearly all sirens manufactured in the United States during 1981/82. This document would be helpful in selecting specific equipment for a warning system, and should be referred to for additional information on sirens, radio encoders, decoders, and related systems.

2. BACKGROUND

2.01 EMERGENCY WARNING PROCEDURES

The purpose of a warning system is to alert the general public to an emergency situation. The most common means of emergency notification employs fixed sirens that produce warning sounds meant to be heard and recognized outside as well as inside office buildings, homes, and cars. Once recognized, these warning sounds are often understood to mean that detailed emergency information is being broadcast over the Emergency Broadcast System (EBS). When an EBS radio or television station is activated, a bulletin from the local authorities responsible for emergency management is read. This bulletin may explain the nature and severity of the emergency, as well as any recommended actions to be taken (perhaps emergency sheltering or evacuation). Primarily, the role that a siren warning system plays is to alert the population to an emergency, prompting them to seek further information from the news media.

While this document deals with numerous types of warning systems, those using fixed sirens are dealt with primarily because they are employed most often. In addition to fixed sirens, warning systems may be composed of, or also rely upon, the following:

- Mobile sirens
- Tone alert radios/NOAA
- Telephone dialers/switching equipment
- Power line carrier/modulation

There are other warning systems that use steam whistles, strobe lights, etc. These are not included in this document since their application is generally on a small scale and they only have limited use. However, the communications and control of the warning systems listed are discussed. These include telephone and direct line systems as well as radio-activated systems. More detail is provided for radio-

activated systems since they are most often used in current large-scale warning systems.

2.02 SIREN SYSTEM OVERVIEW

Warning systems, especially siren systems, came into widespread use during World War II primarily to warn against air raids. Civil defense organizations were mostly responsible for the use of such systems. During these war years and from that time on, more warning systems came into being and were generally tested weekly or monthly. The sirens used in these earlier periods were omni-directional, electro-mechanical sirens with output power levels in the 100 to 115 dBC range. These same sirens also found extensive use as a means of organizing volunteer fire departments. In most cases, this was the fastest way to inform volunteer fire fighters of an emergency.

Such systems found extensive use in small, sparsely populated towns relying on volunteers and were usually activated locally by a switch or by some direct line from the office receiving the emergency call. The number of sirens rarely exceeded one or two and the siren warning signal for fire varied from town to town. These sirens were also used as part of civil defense systems or were used in civil defense exercises. When such sirens had dual purposes (fire and Civil Defense) it became necessary to establish siren sounds that could be recognized for these different purposes. The establishment of different siren sounds that could be used to alert included sounds(6) for an attack warning, an emergency alert warning, and a fire warning.

2.02.01 Attack Warning

The attack warning is a three to five- minute, wavering tone, often referred to as the wail sound. It means is that an attack has been detected and protective action should be taken immediately. Note that this sound requires that immediate action be taken, unlike the other siren sounds implying that the population tune into additional information being broadcast on radio, television, etc.

2.02.02 Alert Warning

The attention, or alert warning, is a three to five-minute, steady tone. It has several meanings, including that an attack <u>might</u> occur or that some peace-time emergency may occur, such as a tornado, tidal wave, nuclear plant emergency, etc. In any case, the sound means that additional information is forthcoming and will advise as to what action is necessary.

2.02.03 Fire Warning

Fire warnings vary from one locality to another, but usually is a steady tone that is turned on and off several times and usually does not last longer than one or two minutes. There are, however, many varieties of fire siren warnings. In any case, the population notified should be made keenly aware of the particular siren sound in their area and act accordingly.

From these earlier years, sirens evolved into more powerful units and their design changed to accommodate different system requirements. Currently, the most widely used sirens are the rotating, directional sirens with output power levels in the 123 to 127 dBC ranges. These sirens were developed for greater coverage capability. By taking an existing 115 dBC rated omni-directional siren and concentrating the output sound in a narrow beam, it becomes possible to raise the output power level. In such cases, two manufacturers designed a horn and then mounted this in a manner to rotate, thereby gaining a 360° siren sound coverage.

Other omni-directional sirens were developed with more powerful motors that raised the output levels to the 120 to 125 dBC range. Today, the most powerful siren manufactured in the United States is a rotating, directional electromechanical siren rated at 135 dBC. Installation of such sirens requires certain considerations in ensuring that the human ear would not suffer damage from the siren sound level when in close proximity to the siren. The Occupational Safety and Health Administration states that sounds greater than 120 to 125 dBC can cause permanent hearing damage. As a result, sirens with outputs above 120 dBC must be

placed in areas where the general public is not granted easy access and therefore, these sirens will not pose a hearing hazard. This is usually done by mounting the siren at a height that keeps the nearby siren sound above ground. The at ground levels are then below 120 dBC.

Within the last five years, certain developments in electronics have allowed electronic sirens to have output power ranges similar to those of the electromechanical sirens. Electronic sirens differ from electromechanical sirens in that they produce sound electronically similar to a public address system, rather mechanically where an electrical motor rotates blades or is designed to store compressed air. The power drivers in electronic sirens are the key element in producing enough power to be as effective as the electromechanical sirens. Electronic circuitry is used to develop the different sounds and can be easily designed to operate at different frequencies. However, the major functional difference is that electronic sirens have a public address voice capability and are, in effect, very powerful public address systems. In addition, since these sirens require much less power to operate and use DC voltage instead of AC for operation, they are operated from batteries. Generally, two 12-volt batteries similar in capacity to those used in large trucks are used to power electronic sirens. As a consequence, these sirens have automatic back-up power and can function when primary power is lost. Most currently available electronic sirens have outpower levels in the 115 to 125 dBC ranges.

2.03 MOBILE SIRENS

Mobile sirens often supplement fixed siren warning systems where it is impossible or not cost-effective to install fixed sirens. In actual practice, they are also the backup to a fixed siren system. The major advantage of mobile sirens is their low cost, while the disadvantages include the delayed warning process due to weather or traffic conditions. Effectiveness is also brought into question because of the similarity between mobile sirens and routine emergency vehicle (such as ambulances and fire equipment) operation. The driving public must somehow distinguish the mobile siren as a warning rather than an approaching emergency vehicle

whereby they immediately clear the roadway ahead. Since the mobile siren vehicle usually uses the public address capability (assuming it is installed) and travels very slowly, it is generally distinguished from a high-speed emergency vehicle. When mobile sirens are heard for periods longer than a minute, they are likely to produce an attention-getting affect. When this has been tested as part of warning system exercises, it is readily apparent that some type of special emergency exists.

The coverage area of mobile sirens however, is limited to areas adjacent to roadways(14). Also, mobile sirens are generally installed to project sound in front of the emergency vehicle. This means that a mobile siren vehicle, when used to warn people indoors, should be pointed toward houses, if possible. Also, mobile sirens do not have the same output power capabilities as fixed sirens. Mobile siren output power is rated in dBC at 12 feet as comparable to fixed sirens, which are rated at 100 feet.

Studies have shown(15) that the effective range of mobile sirens for alerting people in automobiles can range from a few feet to 400 or 500 feet. This cannot be compared directly to warning people in homes but, most likely can be implied, based upon sound transmission losses and the similarities between automobiles and typical homes. It does appear that the effectiveness of mobile sirens is determined most by the speed at which the vehicle travels (and, therefore, the length of time that the sound is heard), the distance the siren is from the person or home, and the direction in which the vehicle is pointed.

2.04 TONE ALERT RADIOS

As mentioned previously, sirens have been used extensively for volunteer fire departments. In the last decade, many of these sirens have been replaced or supplemented by tone alert radios. Tone alert radios are radio receivers that operate in a muted mode, requiring a special coded signal to activate the entire receiver which then receives and broadcasts a message to the listener. These radios usually have a light or buzzer that is activated when a special code is received. This buzzer or light serves the same purpose as a siren, i.e., warns of an

emergency. Of course, the advantage is that the message usually follows immediately.

There are many applications for tone alert radios. These include pagers or "beepers" that are small enough to be attached to belts or carried in pockets. Tone alerts are also used for police emergencies and are often placed in schools, hospitals, and homes of selected officials. Another widespread application is the service offered by the National Oceanic and Atmospheric Administration, National Weather Service often referred to as NOAA Radio or NWS Radio. Here, the NWS continuously broadcasts weather and other information. Such radios are available commercially and can also be operated in a muted mode. This condition is then used when there is no need for continuous forecasts. However, the NWS can transmit a code that would activate the receiver during an emergency condition. This system has also been incorporated into some warning systems through the cooperation of local authorities and NOAA. Other tone alert radio systems operated by police and fire services use radios that are purchased from a variety of manufacturers and operated from the transmitters belonging to these local authorities.

All of these tone alert radios are part of some form of communication system. Someone is licensed to operate a transmitter on a certain frequency at a specified power level. The power level, to a large extent, determines the coverage area of these systems. Obviously, these coverage areas vary. However, most police and fire radio transmitters provide a nominal 20- to 50-mile radius coverage at power levels adequate to reliably activate tone alert radios. Pager systems have a similar range and NOAA radios often have larger ranges due to higher output transmitter power. The addition of transmitter repeaters can greatly extend the range of these systems and are often used when extended area coverage is required.

2.05 TELEPHONE SYSTEM

Another supplement to warning systems includes the telephone system. The technology now exists to automatically dial many telephones (e.g., 50 to 100)

simultaneously. Such systems, however, are very costly compared to tone alert radios and siren systems. As a result, telephone communications are used on a more limited basis and often form only the central communication links in many warning systems. This is done by leasing dedicated telephone lines from the telephone companies. These lines are separate from the normal telephone traffic and switching units which means that their use will not be affected during an emergency when public telephone service may be interrupted. Consider that a typical public telephone system can accommodate 12 to 25 percent of its customers at one time. This means that in certain emergencies, when more than this number attempts to use the phone system, they will be unable to complete a call. This is another reason why a large-scale telephone warning system is limited in capacity. The telephone leased lines can connect major organizations and various schemes can be used. Such systems are often called "hot lines, ring-down lines, dedicated lines," etc. What they all have in common is that they provide a secure uninterruptable system for transmitting information and are not affected by other uses of the telephone system.

2.06 POWER LINE DEVICES

A new technology has been perfected in the last few years, which sends a signal over the power distribution network of a utility. Such systems are called power line carrier signaling systems or power line modulation devices, and were initially developed as an energy-saving method to turn appliances on and off such as water heaters so as to conserve energy. These systems were also used to determine electrical usage. They have since been adapted to warning systems where a device is attached at the point where electrical power enters a structure. This device may turn on a light or sound a warning system and can be used to warn people of an emergency both inside and outside of a house. These systems, at this time, may be only cost-effective as parts of warning systems when used in a dual role such as warning and energy conservation. They do, however, have potential for wide-scale use as additional uses become known.

3. WARNING SYSTEMS – GENERAL DISCUSSION

The majority of warning systems use sound to get the attention of the general public. This sound can be from a fixed siren, a mobile siren, a radio-equipped siren with some audible device, or a small siren attached to a power line meter. This chapter provides an overview of several representative systems. This is followed by a discussion of mobile sirens, radio tone alert devices, and power line warning devices. Note that, most often, the latter three are only a small part of a larger warning system. Such systems are siren-based and the radio tone alerts usually are used for special applications.

3.01 FIXED SIREN SYSTEM OVERVIEW

In some cases, when a listener hears a siren sound, the action to be taken (i.e., take cover, tune in to the Emergency Broadcast System, etc.) is immediately understood. For warning systems designed to alert for nuclear emergency or attack, the sound heard means take cover. Some civil defense warning systems also warn against impending natural disasters such as tornados or floods. Still, the main purpose of most warning systems installed around nuclear power plants is to tell the general public that there is a problem and that they should turn on their radios or televisions for further information.

Examples of these systems are the Washington Area Warning System (WAWAS), the Cedar Rapids/Duane Arnold System, and the Calvert Cliffs System. Each of these systems will be described so that a comparison can be made between them.

Briefly, the WAWAS system is a nuclear attack and warning system; the Cedar Rapids/Duane Arnold System is intended for nuclear attack and warning, natural disaster warning, and nuclear power plant warning; the Calvert Cliffs System is mainly a nuclear power plant warning system.

All of these systems use sirens as the main device for alerting the general public. However, each of these systems has some form of direct communication with the Emergency Broadcasting System (EBS) and other local, county, state, or federal authorities.

3.01.01 WAWAS Overview

WAWAS is the largest known siren warning system in the world. This system has 466 sirens located in the Washington, D.C. Metropolitan Area, covering over 700 square miles that include parts of the surrounding Maryland and Virginia suburbs. All of the sirens are electromechanical rotating directional, rated at 123-125 dBC. Most are installed on poles near public schools or other public property. The system is tested monthly on every second Wednesday.

WAWAS is owned by the federal government and controlled and operated by FEMA from their control center in Olney, Maryland. The major purpose for this system is to warn the general public of an enemy attack or peacetime disaster. The entire system is controlled by leased telephone lines. To activate the system, the control center operator need only dial a telephone number. There are also other activation points for this system, which can serve as back-up control centers.

Note that this system is capable of giving two distinct signals, i.e., the attack warning and the attention alert. When tested, a steady tone is given that lasts for 1½ minutes. As a result of this testing, it has been shown that a failure rate of 5 percent can be expected from this system. These failures are mostly caused by siren failure or some failure associated with the telephone communication system. There has never been an operator-caused failure during the life of the system.

In addition to the sirens, over 150 federal and local buildings have a bell and light system that is activated by WAWAS to warn indoor subscribers. Also, there are communication terminals and a VHF-FM radio system that provide direct communication with various locations.

3.01.02 Cedar Rapids/Duane Arnold Overview

The City of Cedar Rapids, Iowa has had a warning system installed for some 30 years. Its main purpose is to alert people to impending natural disasters (mostly, tornados), as well as nuclear attack. This system was installed using nearly 21 electromechanical omni-directional sirens rated at 123-125 dBC.

After the Duane Arnold Nuclear Power Plant began operation near Cedar Rapids, the utility company installed a warning system. This is required by NRC for possible nuclear power plant emergencies. The outer extremities of the Emergency Planning Zone (EPZ) around Duane Arnold, however, included part of the Cedar Rapids System. As a result, the two systems were integrated into one system with two control centers. Since two counties form the EPZ, the sheriffs in the respective counties, as well as the Civil Defense Agency in Cedar Rapids, are able to activate the entire system.

The system is primarily a siren warning system for the general population. The sirens installed outside Cedar Rapids are electronic sirens with public address capability. These are omni-directional and rotating directional electronic sirens. The directional sirens are rated at 123 dBC and the omni-directional at 115 dBC. Therefore, the system has a mix of siren types. However, since the electronic sirens can provide the same siren signals (except for the specific frequency) as the electromechanical, integration of both siren types was not particularly complicated. The electronic sirens are radio-activated, where as those in Cedar Rapids are controlled by leased telephone lines.

This system, therefore, has three major purposes: nuclear attack warning, nuclear power plant emergency warning, and natural disaster warning. The latter is considered very important since one or more tornados per year are usually seen in the immediate area. The State of Iowa averages 35 tornados per year.

This siren mix of nearly 23 electromechanical sirens and 27 electronic sirens has been combined so that they form a unified system of 50 sirens. The electro-

mechanical sirens in Cedar Rapids were installed starting in 1952 while the electronic sirens were installed in 1982. Eventually, the entire system will be under radio control. The system covers a 10-mile radius, and includes parts of Cedar Rapids outside these 10 miles. Monthly testing has proved to be a valuable aid in training the personnel who will operate the system. This frequent testing has also helped identify malfunctions in the system. The control centers' direct communication lines (leased telephone) to the local EBS network are tested weekly. Also, since there are two counties in the EPZ, the system has been designed so that either county can activate the sirens of the other in case of power failure or similar problems. This cross activation is also tested monthly during the siren tests.

3.01.03 Calvert Cliffs Overview

The Calvert Cliffs Nuclear Power Plant in Calvert Cliffs, Maryland has installed a siren warning system according to the specification of NUREG 0654, dated November 1980. This system uses electromechanical sirens that are omni-directional and directional sirens. The system is intended mainly for warning during a nuclear emergency at the power plant. The area covered is the EPZ around the nuclear power plant, which is roughly a 10-mile radius. Three counties are included in the system and each county activates the sirens in its own county by radio from the dispatch center for the County Civil Defense Center.

In this 10-mile EPZ there are approximately 62 sirens. However, nearly half of the EPZ is composed of the Patuxant River and the Chesapeake Bay, which means that about one-half of the EPZ is water covered. Of the three siren models used, most are rotating directional sirens rated at 123-125 dBC. There are a few omni-directional sirens rated at 113-115 dBC and several small sirens rated at 86 dBC. These small sirens are used in isolated areas for warning several houses that are within a few hundred feet of the siren.

The siren system is tested monthly along with other communication systems. Each county activates its own sirens independently by radio from the respective Civil Defense Headquarters.

3.01.04 Comparison of the Three Systems

The previous paragraphs describe three different siren warning systems. In comparing warning systems, it is important that only similar systems be compared. This usually means that system size and function should be similar to make a comparison, then population density and topography can be considered. While there are many other factors, those considered here have the greatest impact on system design.

Using these criteria, the WAWAS System should not be compared to the Cedar Rapids/Duane Arnold and Calvert Cliffs Systems. WAWAS covers an area at least twice as large and, unlike the other two systems, has an urban population as opposed to a rural population. Its purpose and initial design is intended mainly for nuclear attack warning. Also, the system was not designed according to any current guidelines.

WAWAS, however, does give the best indication of what can be expected for system reliability. This system has an on-going maintenance program and is tested monthly. In its many years of operation, the system has averaged a 5 percent failure rate. This means that, on average, 20 to 25 sirens fail during the monthly tests. All of the failures are caused by electrical or mechanical problems, not operator errors. Such failures usually indicate that either the siren or the communications switching has malfunctioned. Note, however, that these statistics are for complete siren failures and that there are no statistics on whether the siren output signal levels have degraded from their original specifications (which would create a loss in system effectiveness that is not easily measured).

On the other hand, the Cedar Rapids/Duane Arnold System and the Calvert Cliffs System can be compared. Both cover approximately the same area (320 square

miles) and were primarily designed to warn against emergencies at nuclear power plants and natural disasters. The major difference is that approximately half of the Calvert Cliffs 10-mile EPZ is covered by water. The remaining portion is mostly composed of rolling farmland, with a good portion of woodland. The Cedar Rapids/Duane Arnold System is mostly all land area, covering rural farmland that is almost flat with a small amount of wooded area. The portion of this system that includes the City of Cedar Rapids contains about 23 electromechanical sirens. This part encompasses about 15 percent of the circular 10-mile EPZ. The major remaining land area (85 percent) is mostly farmland, with 27 electronic sirens.

From this information, one of the major comparisons that can be made is that more than twice as many sirens are used in the Calvert Cliffs System for half the land area, compared to the Cedar Rapids/Duane Arnold System. Note that this comparison does not take into consideration the sirens in and around the City of Cedar Rapids. Though they differ in model number, the sirens used for each system are nearly equivalent in output power rating. The question can then be asked, what is the major difference between these systems? In fact, the major difference is the background noise level. For Cedar Rapids/Duane Arnold, the average background noise is assumed to be 50 dB, where as at Calvert Cliffs, it was assumed to be 58 dB. As a consequence, siren coverage is assumed to be much greater in the Cedar Rapids System than in the Calvert Cliffs System. Also, the terrain in Cedar Rapids/Duane Arnold is nearly flat compared to that of Calvert Cliffs, where more wooded area tends to further attenuate sound. All of these factors indicate that less siren sound attenuation occurs at Cedar Rapids/Duane Arnold.

In effect, these factors translate into a coverage area, per siren, of no more than a one-mile radius from a 125 dBC siren in Calvert Cliffs to nearly a two-mile radius for the equivalent siren at Cedar Rapids/Duane Arnold. Of course, there are many other variables (such as population distribution) that affect siren coverage. Also, other means to warn people, such as mobile sirens, usually supplement the fixed siren warning system.

The point to consider, however, is that major differences occur in the number of sirens required for a warning system. In this regard, the greatest factor is that of assumed background noise level, and how much the siren sound is attenuated at various distances from the siren. Other factors that affect such designs, such as weather conditions, topography, etc., are discussed in more detail in the following chapters.

4. WARNING SYSTEMS – TECHNICAL DISCUSSION

Most of the warning systems discussed in this document use sound as their means of alerting the public. This sound may be from fixed sirens, mobile sirens, a ringing telephone, etc. Even tone alert radios usually use a buzzer or tone device to gain the attention of listeners. Since what these systems have in common is their use of sound, the following paragraphs discuss the technical aspects of hearing, as well as how sound is propagated, attenuated, and measured. This information is then used to show how effective a warning system can be in different environments.

4.01 BACKGROUND NOISE LEVELS – HEARING AND THE dBA and dBC SCALES

Present sound level criteria for siren warning systems require the sound level to be 10 dB above average outside background noise levels. As stated in NUREG 0654, Appendix 3(11), one reason for this is to provide a distinguishable signal inside average residential structures under normal conditions. Where special cases require a higher alerting signal, NUREG 0654 advises that means other than a widely distributed acoustic signal be used. For outdoor warning, NUREG 0654 recognizes that a person is capable of hearing a siren sound whether it is above or below this ambient background noise level.

4.01.01 Hearing

In practice, the human ear acts like a series of overlapping, constant percentage bandwidth bandpass filters(2). What this means is that the ear can detect sounds in one frequency band while acoustical noise is higher in adjacent bands. This allows a person to hear a sound, such as that produced by a siren, even though it may be below the measured background noise level. This, however, does not mean that such a sound would alert the listener. This problem is discussed in the Outdoor Warning System Guide(30), as follows:

"Hearing — Whether the amount of sound available to warn people will indeed be sufficient to do the job depends upon several factors. First, the warning sound must be audible above the ambient, or background noises. These ambient noises change constantly in loudness and pitch, depending upon noise-producing activities in the vicinity of the listener. Second, the warning sound must get the attention of the listener away from what he is doing. Normally, people "close out" of their minds distracting sounds that are not pertinent to what they are doing. A warning sound must penetrate this mental barrier. Tests have shown that to attract a listener's attention away from what he is doing, a warning sound must be about 9 dB (C) greater than would be sufficient to make it audible to someone who was concentrating on listenting for it, and not doing anything else."

To determine the actual background noise levels, a calibrated sound level meter is required. There are several manufacturers of sound level meters and those that are designed to comply with the American National Standards Institute S1.4 1971 for sound level meters are considered acceptable(1). Many of these meters contain several scales, but when background noise levels are of interest, the dBA and dBC scales can be used.

4.01.02 Sound Level Meters and the dBA and dBC Scales

Initially, these scales were devised for different reasons. In general, the average human ear can respond to frequencies between 20 to 20,000 Hz. However, not all frequencies in this range are heard equally as well as others. The frequencies between 500 and 5,000 Hz are more easily detected by the human ear. Also, there is a condition of the human ear that involves masking of low-frequency sounds by a band of noise that is over one and a half octaves greater than low-level noise(33). These conditions, as well as others, resulted in establishing both the dBA and dBC scales.

4.01.03 Hearing and Sound Level Meters

For most sound meters, the range of frequencies is summed in a manner to arrive at a single reading. This frequency range is limited mostly by the response characteristics of the microphone of the meter. When the energy at all frequencies in the electrical signal from the microphone is summed equally, the quantity measured is the C-weighted sound level. The A-weighted scale, however, filters those frequencies below 600 Hz in such a manner that the scale is the reciprocal of an equal loudness curve at 40 phons, and roughly approximates the reciprocal of the auditory sensitivity of pure tones. Here, the manner in which the acoustical energy is summed is potentially similar to the way the ear may operate. However, to the extent that the ear does not sum acoustic energy, but processes energy at different frequencies in a parallel fashion, the A-weighted network may serve to measure the overload equally to the inner ear for different frequencies. This is an "after-the-fact" use for the A scale since it was originally designed to simulate the action of the auditory mechanism in judging loudness of weak sounds(9).

In simpler terms, the C scale averages all energy in the hearing range nearly equally. The A scale filters, or attenuates, those lower frequencies potentially similar to the way that the ear attenuates lower frequencies. In terms of average daily background noise levels, readings taken on the dBA scale will be generally at least 8 to 12 dB less than readings taken on the dBC scale. Also, readings of most siren output signals will be 1 to 2 dB less on the dBA scale than the dBC scale. Refer to Figure 4.1, which illustrates the dBA and dBC scales relative to frequency. Note also that this scale shows the distribution of siren output frequencies of most fixed sirens manufactured in the United States. This figure shows the steep decline in signal level response in the A scale for low frequencies. Also, the scales are nearly equal between 600 Hz up through the hearing range.

Tests conducted in a house, office, and the outside environment are listed in Table 4.1 and show the types of response received when taking background noise level readings with two sound level meters side-by-side, recording on the dBA and dBC scales. A brief summary of the data collected indicates that sounds such as heavy trucks on a freeway and overhead jet aircraft register 4 to 6 dB higher on

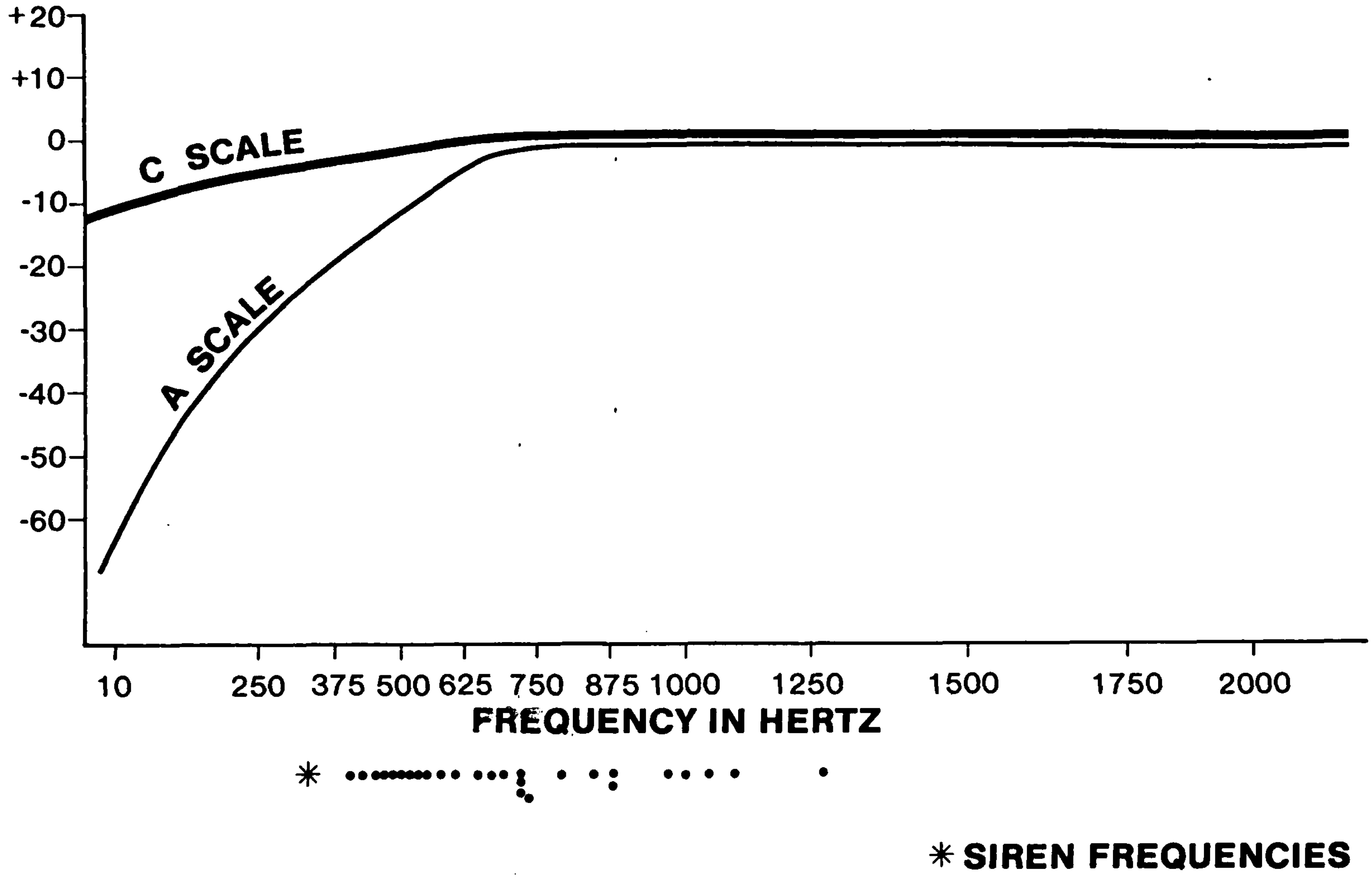


FIGURE 4.1. dBA/dBC SCALE RESPONSE VERSUS FREQUENCY

TABLE 4.1. BACKGROUND NOISE LEVEL MEASUREMENTS
dBA VERSUS dBC SCALE

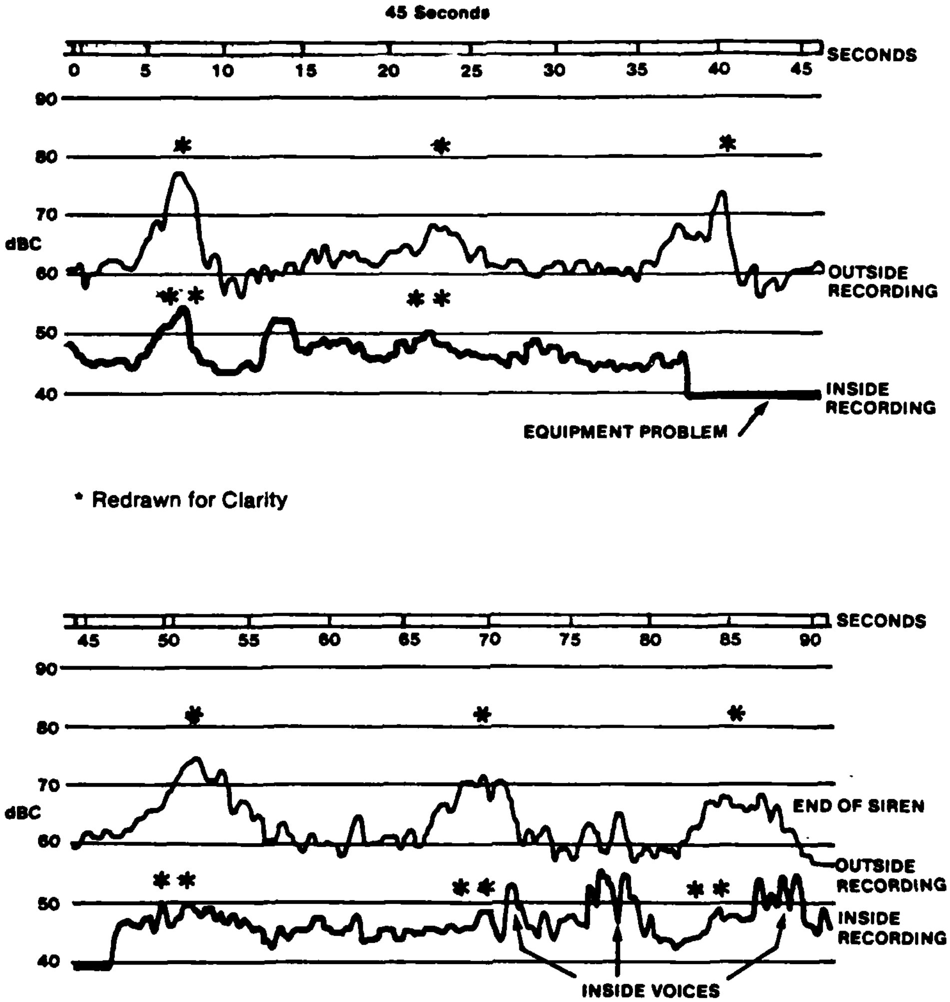
Typical Readings dBA	dBC	Location	Observation
40	40	In house/basement with carpeting and furniture, daytime 10 a.m.	Both scales—same reading under very quiet conditions
40	44	See above	C scale registered 44, reason was noise from refrigerator motor 20 feet away in another room
37-40	56-60	Office—working hours	Office with in-room heater office building (6-storey) central fans in operation
45	56-62	Office—working hours	Office fan on low
47	59-62	Office—working hours	Office fan on high
65-70	66	Office—working hours	Office telephone ringing five feet from meters
70-74	70-74	Office—working hours	Office, person coughing
58-62	68-72	Outside—temperature 45°F, wind gusty 5-15 mph, wooded area 40 feet from large building parking lot, 1,000 feet from busy freeway	Typical noise
60-62	70-72	Same as above	Breeze, gusty wind
56	66	Same as above	Wind calm
68-70	78-80	Same as above	Peak reading for jet aircraft flyover; as aircraft leaves area, A scale does not register rumbling jet noise
64-68	70-73	Outside-temperature 45°F, 600 feet from busy freeway	Typical noise dominated by traffic sounds
68-72	70-78	Same as above	Heavy truck noise

the C scale. For a person coughing, however, both scales register equally, but a telephone at five feet registers 4 dB higher on the A scale than on the C scale. Otherwise, in most test areas, the A scale reads 6 to 12 dB lower than the C scale for background noise measurements.

4.01.04 Measuring Sound and Background Noise

It should be noted here that most background noise measurements are taken in what might be described as a sterile environment; that is, the person taking the readings usually does not make any noise by walking, talking, etc. In this way the background noise, minus people, is recorded. In those cases where background noise is being recorded, as is expected, increased readings occur when people merely start a conversation or some action is taken, such as walking on gravel or dry leaves. This type of noise is often not included in generalized figures for background noise levels. Such noises or sounds are usually put in another category. Notice the inside recording in Figure 4.2. This represents the background noise level. When conversation is introduced into the background, however, this level increases by nearly 5 to 10 dB. Furthermore, the speaker and listener in this example actually experience speech levels much greater than 10 dB above the background noise. In fact, with a background noise level of 41 dBA, speech, at a very low but intelligible level, reads 60 to 65 dBA at 18 inches from the microphone. The dBC scale reading would be 62 to 68 dBC.

There are many other reasons for taking background noise level measurements. These include cases where communities are concerned about particular types of noise, such as aircraft, or when workers need to be aware of the amount of noise given off by machinery. In these cases, noise level readings are usually directed at identifying those noises emitted by the object under investigation. Where this is required, the noise level readings are usually directed at identifying the noises emitted by the aircraft, other machinery, etc., and not necessarily, from the entire background. For example, a special manufacturing machine will emit sounds centered around a certain frequency. To measure this particular frequency and not others, octave or 1/3-octave filters are used in conjunction with the sound level



* Maximum Outside Siren Signal Level

* * Maximum Inside Siren Signal Level

Sound propagation loss outside to inside ranges from 21 - 26 dB differential. Readings from split level home, 15 years old with inside meter 10 feet from large window in line to siren. Maximum outside siren signal 77 dBC. Maximum inside siren signal 55. Doors and windows closed, temperature 54°F, wind 0-6 mph. Siren 1500 feet from home (ACA Allerator).

FIGURE 4.2. INSIDE SIREN SOUND PROPAGATION TEST

meter. These filters pass the frequencies and sound of interest and attenuate, or filter, those outside this band. As a comparison, the dBA scale can be considered as attentuating frequencies below 600 Hz much more than does the dBC scale. For overall background noise level measurements, however, octave or 1/3-octave filters should not be used. An example of typical background noise levels using the dBA and dBC scales at the same point in time is shown in Figure 4.3. Notice that the dBC background levels average 8 to 12 dB higher than those on the dBA scale. Also, in Table 4.1, the results of background noise tests using both scales are given to show a comparison of the types of noises and how they differ when measured on these scales.

When taking the actual sound level and background noise level readings, there are several techniques that must be considered. Background noise readings are essentially the sounds of the environment and are emitted from many sources. As a result, this presents what is known as a diffuse sound field. The sound level meter, and in particular, the microphone, will be receiving these sounds from all directions. This allows sound meter operators to be less concerned with incorrectly modifying the readings on the meter—as would be the case if the sound came from one source and the operator was very near the meter, or blocked the sound from reaching the microphone directly. In fact, the position of the operator could influence the readings, for example, a sound reflection from the operator, back to the meter might cause a higher-than-actual reading. Blocking the sound path could also lower the actual readings.

Consequently, the recommended method for taking readings is to mount the sound level meter on a tripod 4 to 6 feet above ground and position the operator several feet (e.g., 4 to 10 feet) away from the microphone. When a particular sound source is to be measured such as a siren, the microphone should be pointed toward that source and the operator positioned so that he is not between the source and the microphone. When a tripod or similar device is not available, the operator may hold the meter at arm's length, pointed toward the sound source. The basic rule of thumb is to keep objects that may reflect sound as far away from the meter as possible. Consider the human head, which tends to reflect sound and, in many

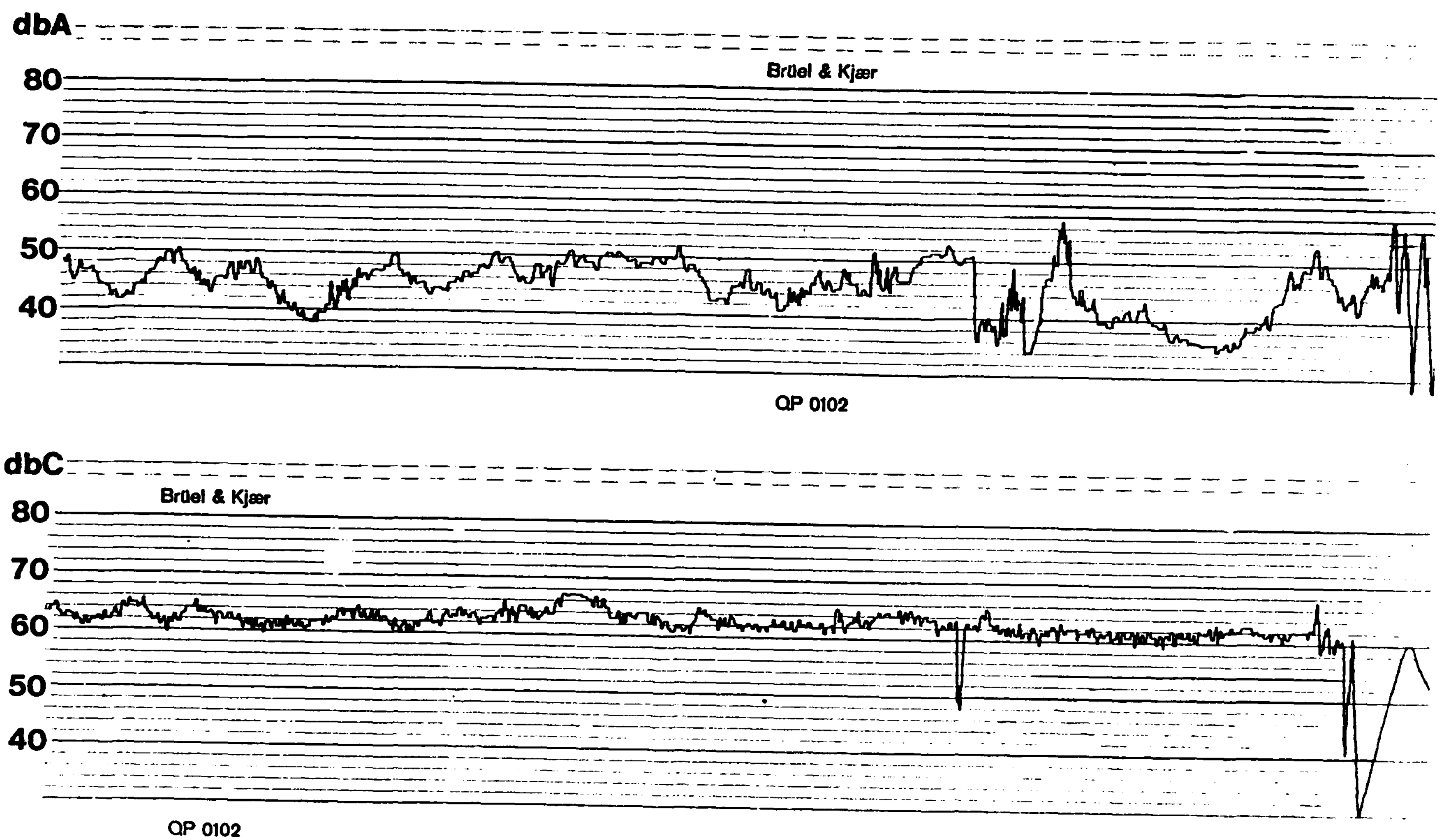


FIGURE 4.3. TYPICAL BACKGROUND NOISE LEVELS A AND C SCALES

cases, actually helps to increase sound levels at the ear by several dB. Measurements have shown that for most frequencies between 250 and 8,000 Hz in a diffuse field, the sound level near the ear canal is 3 dB greater than that which would be measured otherwise. Also, for frequencies from 3,000 to 6,000 Hz, there can be as much as an 11 dB increase near the ear canal(12). This is mentioned to illustrate the importance of using proper techniques in sound level measurement. Further information and assistance is often provided by manufacturers of sound level equipment, and is usually presented in operator's manuals or separate brochures.

Once the proper background noise levels have been established, then the amount of sound power that is necessary to alert the listener in various locations can be determined.

4.02 BACKGROUND NOISE LEVELS AND SIREN SOUND PROPAGATION

Background noise levels can often have the largest impact of any variable on the size and number of sirens required for a warning system. The accepted design criteria for alerting someone is that the sound level be, on average, 10 dB greater than the average background noise level at that point in time. However, the average background noise level can change in some areas. This can be due to seasonal traffic (e.g., to and from beach areas) or may vary hourly, such as might be found on busy highways during rush hour. In any case, a major source of background noise comes from traffic and transportation systems. This includes highways, areas near airports, train terminals, and congested streets in urban areas(7). In suburban and rural areas, wind through trees and insects are major background noise sources. In the work environment, noise sources from machinery, heating and cooling systems, and other office functions make up the major parts of background noise. As a result, background noise will vary and usually is at its highest during the regular working hours of the day. Consequently, this time period is the most likely to indicate what an average background noise level should be for a particular area.

The relationship between background noise levels and sound propagation/attenuation will determine the number of sirens required for a particular area. To do this, assume first that it requires, on average, a siren sound to be 10 dB higher than the average or existing background noise to alert someone. Second, assume that the siren sound will decrease in strength by 10 dB for each time that the distance from the siren doubles. This relationship is shown in Tables 4.2 and 4.3.

In Table 4.4, notice that area coverages and ranges are given for different background noise levels for typical siren outputs. Then observe Table 4.5 to see the difference in coverage when a siren sound level is attenuated at 8 dB, 10 dB, or 12 dB for doubling of distance. This relationship is also shown in Figures 4.4, 4.5, and 4.6, where the relative coverage areas are shown graphically. Notice that Tables 4.2 through 4.4 assume a signal loss of 10 dB for each doubling of distance. However, certain conditions can change this. In cities and highly industrialized areas, the loss may average 12 dB per distance doubling. In quiet, flat open areas, however, it may be 8 dB. In each case, the impact on system design is shown in Figure 4.4 and Table 4.5.

For example, if the background noise level is determined to be 50 dBA for the flat terrain of a circular 10-mile EPZ, then approximately 30 sirens with an output power level of 125 dB are required. If the background noise level is 5 dB higher (i.e., 55 dB), then nearly 68 sirens would be required for full coverage. All this assumes a signal loss of 10 dB per distance doubled. Again, refer to Figures 4.5 and 4.6, which show typical coverage areas for five different siren output levels. These figures are given to show the relationship between area coverage of various sirens and how much area coverage changes with a 2 or 3 dB change in output. The output power levels are typical of the majority of sirens available from five manufacturers.

In these figures, note that a siren with an output of 5 dB less than another has approximately one-half the area coverage. Observe Figures 4.5 and 4.6, and notice that there are circles for five typical siren output levels. These are in the ranges of 125, 123, 120, 118, and 115 dB.

TABLE 4.2. SIREN SIGNAL LEVEL ATTENUATION FOR VARIOUS DISTANCES
(ASSUME 10 dB LOSS FOR DISTANCE DOUBLING)

Distance in Feet	Typical Siren Output dBC Values							
100	125	123	120	118	115	113	110	105
150	119							
* 200	115	113	110	108	105	103	100	95
300	109							
* 400	105	103	100	98	95	93	90	85
600	99							
* 800	95	93	90	88	85	83	80	75
1,125	90	88	85	83	80	78	75	70
1,225	89	87	84	82	79	77	74	69
1,300	88	86	83	81	78	76	73	68
1,400	87	85	82	80	77	75	72	67
1,500	86	84	81	79	76	74	71	66
* 1,600	85	83	80	78	75	73	70	65
1,725	84	82	79	77	74	72	69	64
1,850	83	81	78	76	73	71	68	63
1,975	82	80	77	75	72	70	67	62
2,100	81	79	76	74	71	69	66	61
2,250	80	78	75	73	70	68	65	60
2,450	79	77	74	72	69	67	64	
2,600	78	76	73	71	68	66	63	
2,800	77	75	72	70	67	65	62	
3,000	76	74	71	69	66	64	61	
* 3,200	75	73	70	68	65	63	60	
3,425	74	72	69	67	64	62		
3,650	73	71	68	66	63	61		
3,975	72	70	67	65	62	60		
4,225	71	69	66	64	61			
4,500	70	68	65	63	60			
4,850	69	67	64	62				
5,200	68	66	63	61				
5,575	67	65	62	60				
6,000	66	64	61					
6,400	65	63	60					
6,900	64	62						
7,350	63	61						
7,900	62	60						
8,450	61							
9,100	60							
9,800	59							

*Doubling Distances

TABLE 4.3. SIREN SOURCES VERSUS
MAJOR EXPECTED AVERAGE SIGNAL LEVELS

Sound Level	Siren Source 125 dB	123 dB	120 dB	118 dB	115 dB	113 dB	110 dB	105 dB
	Distance in Feet							
80 dBC	2,250	2,000	1,600	1,400	1,100	950	800	600
75 dBC	3,200	2,800	2,250	2,000	1,600	1,400	1,125	800
70 dBC	4,500	4,000	3,200	2,800	2,250	2,000	1,600	1,125
65 dBC	6,400	5,600	4,500	4,000	3,200	2,800	2,250	1,600
60 dBC	9,100	7,900	6,400	5,600	4,500	4,000	3,200	2,250

Note also that Tables 4.2 and 4.5 show siren sound levels as they are attenuated for various distances from the source. The sound, however, does not necessarily attenuate exactly as shown but, rather, in a manner where attenuation is greater from the source out to approximately one-quarter mile, and then less from this point on. Other tests(29) for urban conditions have shown attenuations of 8 to 11.5 dB per distance doubled out to one-quarter mile. From this point, 6 dB loss per distance doubled applies. In any case, the effective range of a siren relative to background noise can be estimated using these tables only if special local features, such as higher buildings, dense foilage, high hills, etc., are taken into account. The critical estimation for the sound attenuation relative to existing sirens applies for those distances beyond 2,000 to 4,000 feet. Within these distances, most siren typically have enough output power to greatly exceed local background noise levels and, therefore, the amount of attenuation is unimportant.

TABLE 4.4. TYPICAL SIREN COVERAGE AREA (AVERAGE CONDITIONS) WITH VARIOUS BACKGROUND NOISE LEVELS

(Assume 10 dB Signal Loss per Distance Doubled)

Source	60 dB Signal/ 50 dB Background		65 dB Signal/ 55 dB Background		70 dB Signal/ 60 dB Background		75 dB Signal 65 dB Background		80 dB Signal 70 dB Background	
Typical Siren Output Level	Coverage (Square Miles)	Area Radius (Feet)	Coverage (Square Miles)	Area Radius (Feet)	Coverage (Square Miles)	Area Radius (Feet)	Coverage (Square Miles)	Area Radius (Feet)	Coverage (Square Miles)	Area Radius (Feet)
125 dBC	10.40	9,600	4.60	6,400	2.28	4,500	1.15	3,200	0.570	2,250
123 dBC	7.00	7,900	3.50	5,575	1.80	3,975	0.88	2,800	0.440	1,975
120 dBC	4.60	6,400	2.28	4,500	1.15	3,200	0.57	2,250	0.290	1,600
118 dBC	3.50	5,575	1.80	3,975	0.88	2,800	0.44	1,975	0.220	1,400
115 dBC	2.28	4,500	1.15	3,200	0.57	2,250	0.29	1,600	0.140	1,125
113 dBC	1.80	3,975	0.88	2,800	0.44	1,975	0.22	1,400	0.110	1,000
110 dBC	1.15	3,200	0.57	2,250	0.29	1,600	0.14	1,125	0.070	800
105 dBC	0.57	2,250	0.24	1,600	0.14	1,125	0.07	800	0.040	600
86 dBC	0.16	1,200	0.07	800	0.04	600	0.01	300	0.005	200

TABLE 4.5. TYPICAL 125 dB SIREN SIGNAL LEVELS AT DISTANCES FOR EITHER 8-10-12 dB LOSS/DOUBLING DISTANCE

Distance From Source (Feet)	Signal Levels in dBC		
	8 dB Loss/ Double Distance	10 dB Loss/ Double Distance	12 dB Loss/ Double Distance
100	125.0	125.0	125.0
200	117.0	115.0	113.0
400	109.0	105.0	101.0
800	101.0	95.0	89.0
1,000	99.0	93.0	85.0
1,500	94.0	86.0	78.0
1,600	93.0	85.0	77.0
2,000	91.5	82.0	73.0
2,500	88.0	79.0	69.0
3,000	86.0	76.0	66.0
3,200	85.0	75.0	65.0
3,500	83.5	74.0	63.5
4,000	82.5	72.0	61.0
4,500	81.0	70.0	
5,000	80.0	68.5	
5,500	78.5	67.0	
6,000	77.8	66.0	
6,400	77.0	65.0	
6,500	77.0	64.8	
7,000	76.0	63.8	
7,500	75.0	62.5	
8,000	74.5	62.0	
8,500	73.8	61.0	
9,000	73.0	60.0	
9,500	72.5		
10,000	72.0		
12,000	70.0		
15,000	67.0		
20,000	64.0		
25,000	61.0		

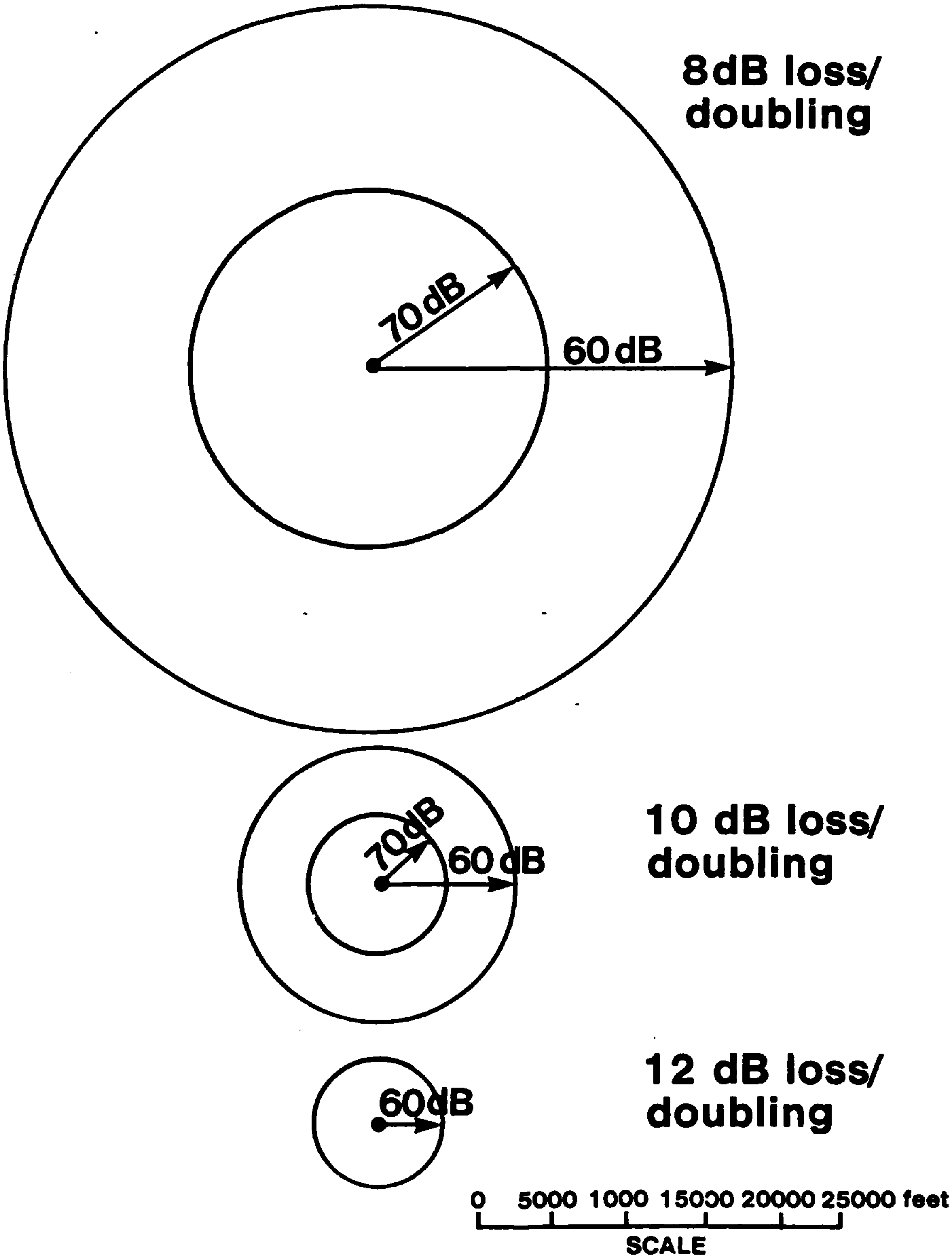
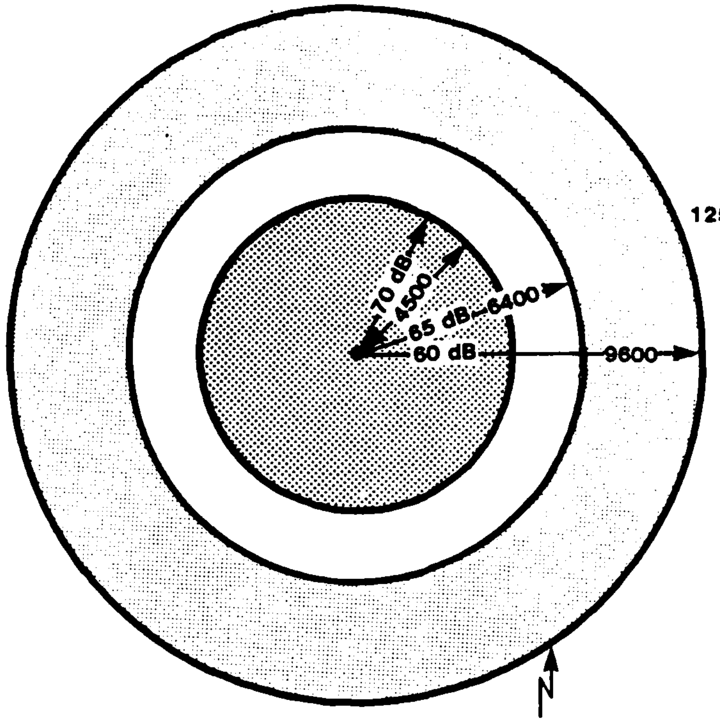
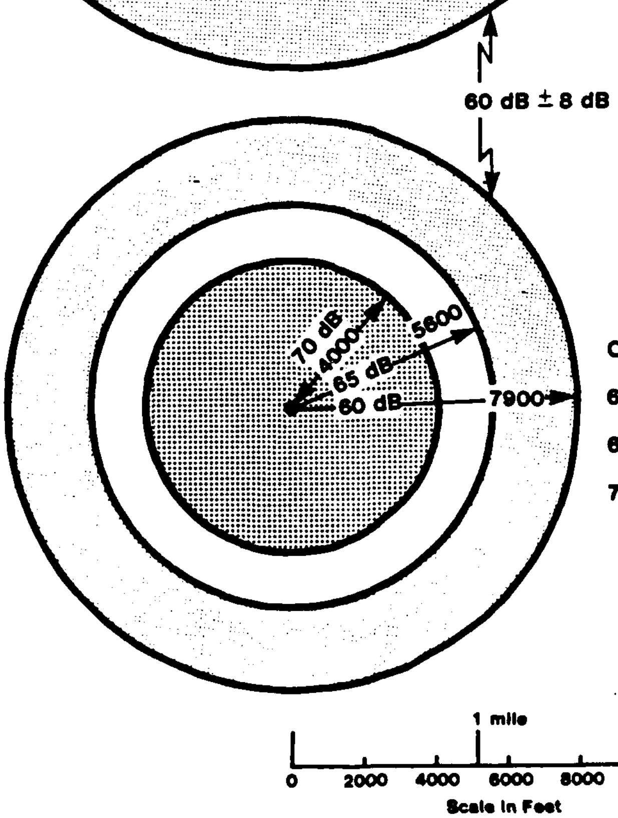


FIGURE 4.4. SIREN SOUND COVERAGE



125 dB Siren

Circle	Square Miles	Sirens for 10-Mile Radius-Area Coverage
60 dB	10.39	30
65 dB	4.62	68
70 dB	2.28	137

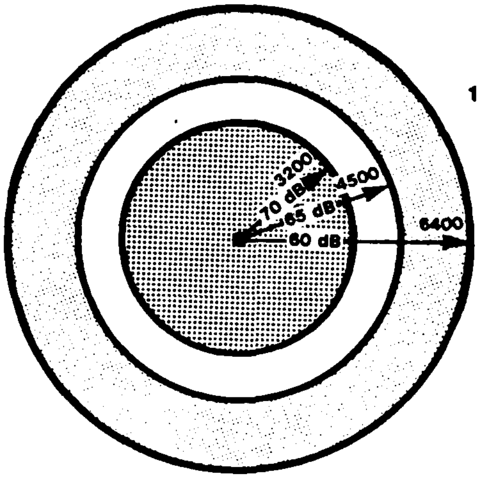


123 dB Siren

Circle	Square Miles	Sirens for 10-Mile Radius-Area Coverage
60 dB	7.0	45
65 dB	3.53	90
70 dB	1.8	174

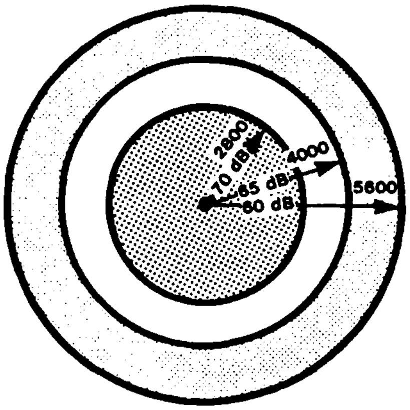
FIGURE 4.5. SOUND PROPAGATION FOR 125 AND 123 dBC SIRENS
(Assuming a 10 dB Loss per Distance Doubling.)

120 dB Siren



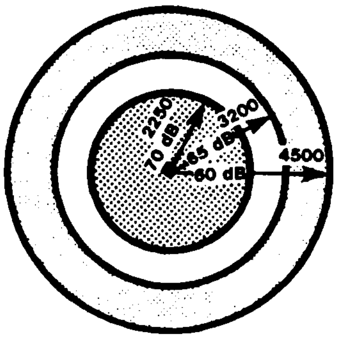
Circle	Square Miles	Sirens for 10-Mile Radius-Area Coverage
60 dB	4.62	68
65 dB	2.28	138
70 dB	1.15	273

118 dB Siren



Circle	Square Miles	Sirens for 10-Mile Radius-Area Coverage
60 dB	3.53	90
65 dB	1.8	174
70 dB	.88	356

115 dB Siren



Circle	Square Miles	Sirens for 10-Mile Radius-Area Coverage
60 dB	2.28	138
65 dB	1.15	273
70 dB	.57	550

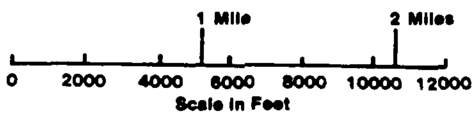


FIGURE 4.6. SOUND PROPAGATION FOR 120, 118, AND 115 dBC SIRENS
(Assuming a 10 dB Loss per Distance Doubling)

4.03 SOUND ATTENUATION FOR DWELLINGS

A sound, as it passes from the outside to the inside of a building, is attenuated, or lessened. How much attenuation occurs depends upon many factors. In regard to siren signals, the most important factors include the type of material and construction of the building that the warning sound must penetrate, and the frequency of the siren signal.

One intuitively expects that sound would be attenuated more by a concrete wall than by a wooden frame wall. When any type of wall has either windows or doors, the attenuation of sound is further affected. Studies have shown(3,4,39) that a six-inch concrete wall produces a sound transmission loss of 27 to 45 dB between 100 and 1,000 Hz. An interior wall shows a loss ranging from 16 to 39 dB. Refer to Figures 4.7 and 4.8, and observe the increase and decrease in transmission loss as a function of frequency. Note that in comparing the lowest siren frequencies (around 390 Hz) with the highest siren frequencies (near 1,275 Hz) the difference in transmission loss is nearly 7 dB. This implies that for alerting people indoors, the lower frequency sirens may be more effective.

In terms of absolute transmission loss through exterior walls of a frame house where windows and doors are installed, the loss is not as great as that shown in Figure 4.7 for solid walls(3). The expected transmission loss from interior walls typical of a home is shown in Figure 4.8. The amount of loss shown(4) is similar to actual test data.

Several tests were conducted where sound level readings were made both outside and inside a split-level, wooden frame home with windows and doors closed during a siren test. These test results are shown in Figure 4.2, and indicate that a transmission loss ranging from 21 to 26 dB was recorded when the peak siren signal was received. The siren tested was a rotating, directional, electromechanical siren, with a dual-tone frequency of 523 or 698 Hz. The strongest signal recorded outside was 78 dBC with a corresponding inside recording of 55 dBC. The inside location of the recorder was 12 feet from the outside wall, which had two windows

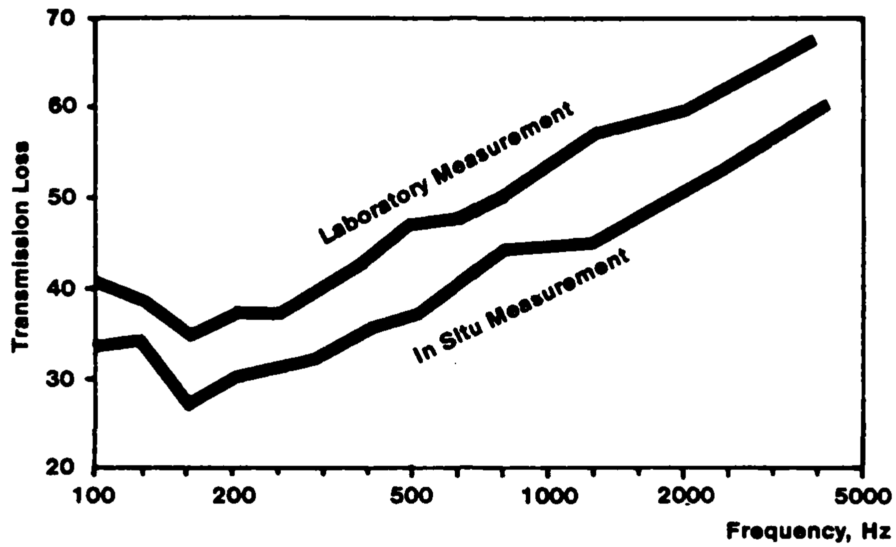


FIGURE 4.7. TRANSMISSION LOSS AS A FUNCTION OF FREQUENCY
FOR A 6-INCH CONCRETE WALL
(No Windows or Doors)

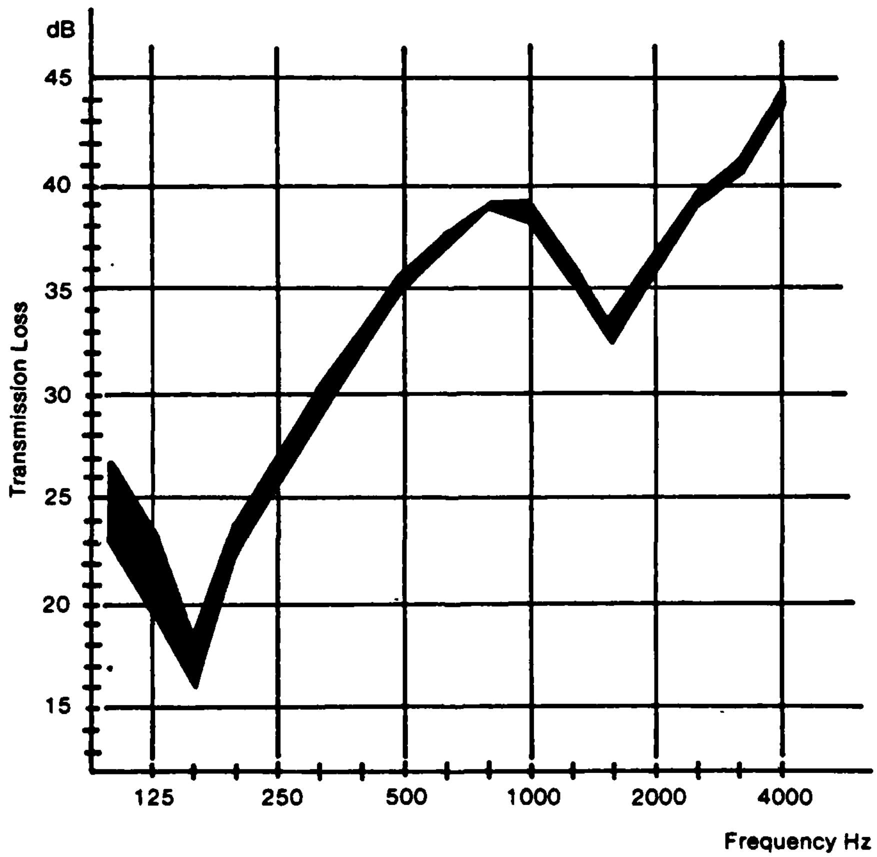


FIGURE 4.8. TRANSMISSION LOSS AS A FUNCTION OF FREQUENCY
FOR INTERIOR WALLS
(No Windows or Doors)

of approximately 12 square feet and a standard sized door. These actual readings are in the range of expected transmission loss as reported in other publications(2, 3). Note that the data shown in Figures 4.7 and 4.8 do not indicate transmission loss when windows and doors are added. In considering the many variables that are introduced by doors, windows, insulation, etc., the data published by the Society of Automotive Engineers are the best currently available for individual homes. For office buildings, which are generally constructed with tightly sealed windows and brick or cement walls, attenuation can be assumed to be at least as great as that of a home with storm windows.

Unlike a solid wall, walls having doors affect the attenuation of sound passage in a different way. The small gaps between the door and door frame, as well as the size of the door, determine which sound frequencies are attenuated more than others. The physical size of the door determines its resonant frequency and, consequently, the amount of signal strength passage. Windows also provide attenuation and generally pass higher frequencies (such as jet aircraft) more easily than lower frequencies. Single windows, typical of residential houses, pass higher frequencies better than lower frequencies. In this range, noises such as traffic, are attenuated better than jet aircraft noise, which is typically higher in frequency. Double-pane windows separated by small gaps (1 to 1.2 cm) such as those used in commercial and office building construction have a resonant frequency around 300 Hz. They, therefore, pass these lower frequencies better than higher frequencies.

From this brief discussion, it can be seen that many factors affect sound attentuation in homes and buildings, and that the degree of attenuation varies, depending upon the frequency of the sounds and the material they must pass through. For the frequency range between 353 to 707 Hz (this is the 500 Hz octave band 3 dB attenuation points) the Society of Automotive Engineers(25) published a summary of attenuation factors that have been used for several years in various applications. Using this information, as well as the data from Figures 4.7 and 4.8, and data from actual tests, the following Table 4.6 is given as a general guide for determining average sound reduction in a single family home(34).

TABLE 4.6. TYPICAL SOUND ATTENUATION FROM OUTSIDE TO INSIDE

	Cold Climates	Warm Climates
Windows/Doors Opened	16-19 dB	12-15 dB
Windows/Doors Closed	27-30 dB	22-25 dB
Storm Windows and Doors Installed	31-34 dB	

Note that where actual siren data was taken (Figure 4.2) the range of attentuation varied approximately ± 15 percent for each time the directional siren was aimed toward the house. It can also be expected that since the frequencies of sirens differ from one model to another, the amount of attenuation will vary. As a general rule, it can be assumed that the lower siren frequency will be attenuated less than those in the higher range by as much as 8 dB. The range of commercially available sirens is from 387 Hz to 1,275 Hz.

4.04 SIREN WARNING SYSTEM EFFECTIVENESS

Warning systems (especially those around nuclear power plants) are comprised of many integral parts. These parts generally include radio and telephone communications, as well as some type of audible warning devices. Audible devices can range from tone alert radios to "beepers" and siren systems. The siren systems, in most cases, alert the largest geographic area and number of people.

Ways of determining how large an area a siren can cover effectively, as well as how many people it can alert, are influenced by three major factors. The knowledge of the listener, the reliability of the system components, and the criteria used in designing a sound coverage siren system all contribute to the range of effectiveness of a siren system.

The first factor to consider in determining a siren's effective coverage is that to warn people outside, a siren noise level should be 10 dB or greater above the average ambient noise level. This 10 dB difference is intended to have an

attention-getting effect. Thus, a person who is preoccupied would be disturbed from his current task and recognize the siren sound. This does not mean that the siren sound must be present continuously, but only to get the attention of people nearby. How each person reacts to a siren sound is determined by whether or not the person:

- Recognizes that it is a warning siren
- Knows the meaning of the siren sound, i.e., what action to take (such as take cover, tune in the radio for further information, etc.)
- Believes, in fact, that a real emergency exists rather than a false alarm or test

The second factor that must be considered is how much of the system will function properly. Major considerations in this regard include:

- How many points (the more points, the greater the probability of operator error) are there for activation of the siren systems?
- What percentage of the sirens will be activated and how many will fail (therefore, what percentage of the people and area will be covered)?
- What percentage of the sirens will be under repair?
- What weather conditions are present at the time of system operation?

Lastly, the criteria used to determine effective coverage when the system was designed must be considered:

- What was the background noise level, and was it measured or assumed?
- Was there at least a 10 dB difference between the siren sound level and background noise, as based upon manufacturer specification?
- Is the amount of power supplied at each siren site sufficient for the siren to operate at 100 percent of published efficiency?

The majority of these factors can be satisfied by the proper design of the system and selection of the individual components that meet the design parameters. For siren systems, this design and selection should be done by applying the criteria given in the following paragraphs.

4.05 SIREN SELECTION CRITERIA AND COMPARISONS

The selection of the type of siren, or sirens, that will be in the system is determined from a variety of factors. Usually a system design has been established which should show the locations of the various sirens, the size (output power level rating), the type (rotating or omni-directional), and in some cases, capability (voice capability dictates electronic siren). Other factors such as the type of communications necessary for activation, etc., are important but seldom affect the siren selection, since these items are common to most sirens. The siren make and model that is selected is usually the key item in satisfying the coverage cirteria established by the system design and affected mostly by the output power level requirements.

If the design calls for a siren of 125 dBC output, regardless of type, it must be understood that a 120 dBC rated siren would not be an adequate substitute. At this point, the tolerance allowance for output power must be established. It is important that when comparing one siren to another, the same methods of comparison are used. The most important characteristic to compare is output power at a point 100 feet from the siren and at the siren height. This is the most widely accepted method of rating siren output power levels and should be used to compare one siren against another. Other methods are used by various manufacturers to indicate the siren output power levels. One method includes the possible additive effects of ground waves from the siren at the 100- or 1,000-foot point from the siren. This usually adds 5 to 6 dB to the siren stated output power levels. This is the optimum sound propagation condition and cannot be relied upon for many types of siren installations. Therefore, siren sound output power levels using ground reflection figures should not be used when comparing sirens. Only the rated outputs on the dBC scale at 100 feet from the siren should be used. This method will permit the user to select reliably between sirens with comparable ratings.

Once the output sound power level is established, usually the primary (voltage/ current) power requirements will affect siren selection. Most often, the avail-

ability of single-phase or 3-phase power at potential siren locations will dictate a siren selection decision. When 3-phase power is not available nearby, the siren selections will be limited to fewer models. This decision actually is based somewhat on a cost-benefit analysis where the additional cost of adding 3-phase power exceeds the costs of going with single-phase siren motors that might have a shortened mean time between failures. At this point, electronic sirens are usually considered since they are battery powered and require only single-phase primary power to maintain their batteries at full charge. Also, should primary power fail, such sirens remain fully functional since they operate on batteries.

Most other items necessary for siren selection (such as mounting considerations, maintenance agreements, warranties, etc.) may vary only slightly from one manufacturer to another. Such decisions are usually dependent on local laws or regulations and do not affect specific siren selection.

There are other criteria that do not necessarily affect the siren coverage decisions, but affect operational control and system reliability. These include the activation method and, if by radio, the type of encoder and decoder used. There are also various construction techniques that should be considered to help prevent false activation of sirens due to line surges, or lightning strikes. These are discussed in another section of this document.

4.05.01 Siren Functional Characteristics

Most fixed sirens are classified as either directional or omni-directional. A directional siren is one that has, in effect, a beam-forming design where the sound is emitted. This design directs the siren sound in a form similar to a flashlight beam The beam width may be around 25 to 30 degrees horizontally and vertically. This beam of sound is then moved as the siren "horn" is rotated. Most rotating sirens operate at 2, 3, 3.5, or 4 rpm. This beam forming allows a siren to have a higher output sound level using the same amount of input power as an omni-directional siren. This increase is usually from 6 to 10 dB.

With one exception, an omni-directional siren outputs sound a full 360 degrees horizontally. The vertical beam width is typically +5 degrees up and 10-15 degrees down. With one exception, directional sirens are designed to rotate and have output levels ranging from 120 to 127 dBC.

The exceptions to the preceding discussion include an omni-dierctional 115 dBC siren with a cloverleaf sound projection pattern and a rotating directional siren with an ouptut signal level of 135 dBC. The 135 dBC siren requires much greater input power and can only be applied in special cases. The cloverleaf siren is an old model not in current production. Neither of these sirens are implied in the following discussions.

4.05.02 Siren Electrical Characteristics

There are two basic ways to produce a siren sound—electromechanically and electronically. Electromechanical sirens produce sound by passing air through the veins or holes of a rotating device. This air can come from either an air compressor or from a combination of rotating and stationary blades driven by a motor. By changing the speed of the rotating units, or by opening and closing air passages, different sounds and tones are produced and the basic siren frequency is established. This is a fixed condition of electromechanical sirens.

All electromechanical sirens are powered from an electrical source. The amount of power that electromechanical sirens generally need to operate is more than that used in a typical home. The effect that this has on siren installation, especially in rural areas, is that occasionally not enough, or only marginal, power is available. When this occurs, new power lines or other power boosting devices may have to be added. The power that is required for the more powerful sirens is not the 115 VAC normally supplied to outlets in a typical home. This power is either 208, 220, or 460 VAC with three phases required. This is also a problem in rural areas where 3-phase power is not always available. Furthermore, the cost to add this power in rural areas can greatly exceed the cost of the siren system itself. The alternative

is usually to add more smaller sirens that can operate on available power, or to use electronic sirens.

Electronic sirens produce their sound in the same manner as a public address system. In fact, the electronic sirens are, in effect, a very powerful public address system. The inherent design of an electronic siren allows for a large variety of signals to be produced as well as providing the capability to transmit voice signals. These sirens, however, are not powered directly by existing electrical power. Instead, all electronic sirens are battery powered. Usually, two 12 VAC batteries (of the size normally used by trucks) are connected in series. This connection produces 24 VAC, which directly powers the siren. Such configurations can apply power to operate an electronic siren for up to 30 minutes. Normally the batteries are being charged continuously to maintain a full charge at a rate close to that used to power a few light bulbs. The power required for charging when the batteries are discharged is similar to that required by an electric heater with power supplied by a typical 115 VAC house outlet. In rural areas, since heavy power consumption is an issue, electronic sirens can sometimes be more cost-effective than electromechanical sirens.

4.06 SIREN DESIGN CRITERIA

There are many factors that determine the adequacy of a siren warning system. Each of these factors impacts the system design and, therefore, influences its effectiveness and cost. Other factors deal with reliability and maintainability. However, it is not sufficient to list these factors, but each factor and its affects on the system must be discussed. Major factors are:

- Background Noise Levels
- Primary Power Availability
- Topography
- Weather Conditions
- Communications Used
- Human Factors and Training
- Testing

All of these factors are discussed in the following pararaphs, except for background noise levels, discussed in earlier paragraphs.

4.06.01 Primary Power Availability

Electrical power is distributed in a manner such that the high voltages generated at power plants are sent over cables to substations or distribution points. At this stage these voltages are fed through step-down transformers that reduce the voltage levels to a value that is manageable during the next phase of power distribution. Other step-down transformers are installed in the local distribution system to bring the voltages down to the levels that are used in factories, stores, various industries, homes, etc. These voltages are in the 115, 220, 440 VAC range with one, two, or three phases. The 115 VAC and 220 VAC voltages are common to homes, where as the 3-phase systems are used in industrial applications where more power is required. As a result, the higher voltages and three phases are commonly found in industrial areas and the 115-220 VAC single- and 2-phase level often occurs in urban and rural areas.

This condition will often affect the decision regarding the type of siren to be selected for a warning system. Some of the largest and most powerful sirens can only be operated with 3-phase power. When sirens of this type are installed in rural areas, the costs of adding 3-phase power for each siren location will, in most cases, exceed the cost of the siren system. One alternative often used in such cases is to select a siren that can operate from either single phase or 3-phase power with the same output power specifications. The major tradeoff is that the electrical motor used in the single-phase siren does not have as long a life expectancy as the 3-phase motor. In effect, the long-term maintenance costs for the single-phase motors may be higher since the motor has a shorter expected life span. The power problem is somewhat more complicated by the fact that the starting power current requirements for typical siren motors are two or more times greater that the operating current requirements. This must be accounted for when the system is installed. Therefore, the power distribution system must be large enough to supply the start-up power as well as the operating power at each siren location.

A second alternative is to select sirens with power requirements that can be met by the existing system. This means that the sirens generally will have a much smaller output sound power capability. Consequently, more sirens would be required for area cover. Refer to Figures 4.5 and 4.6, and observe that for a 5 dB reduction in siren output power level, twice as many sirens are required to provide the same area coverage.

A third alternative is to select electronic sirens instead of electromechanical sirens. Since the electronic siren is battery-operated, only primary power is required to keep its two batteries fully charged. Also, an electronic siren would be operable during a power outage. At rated power, however, it only has a maximum operating time of 30 minutes.

4.06.02 Topography

The topography of an area where sirens are used must be considered in any siren warning system design. It can be assumed that a sound will be attenuated as it strikes a surface and deflects in a different direction. How much of the sound is attenuated is determined by the type of surface and by the number of surfaces. Surfaces such as foam (often used for soundproofing), grass, and vegetation attenuate sound more than solid surfaces such as finished wood, metal, glass, etc. Hills and mountains form very good sound barriers. Sound on one side of a hill reaches the other side by going around the hill and deflecting from other surfaces. Other sound waves will go over the hill. Again, how much of the sound is attenuated depends on the number of surfaces struck and the type of surface. In addition, the frequency of the sound also affects the degree of attenuation. In general, the lower frequencies tend to be attenuated less than the higher frequencies (although this also depends upon the object that the sound is striking).

The positioning of sirens, therefore, must consider the type of sound coverage pattern that can be expected, based upon topography. Figures 4.9 and 4.10 are typical examples of the kind of sound pattern that can be expected when a siren is mounted above most of the surrounding trees and buildings. In relatively flat

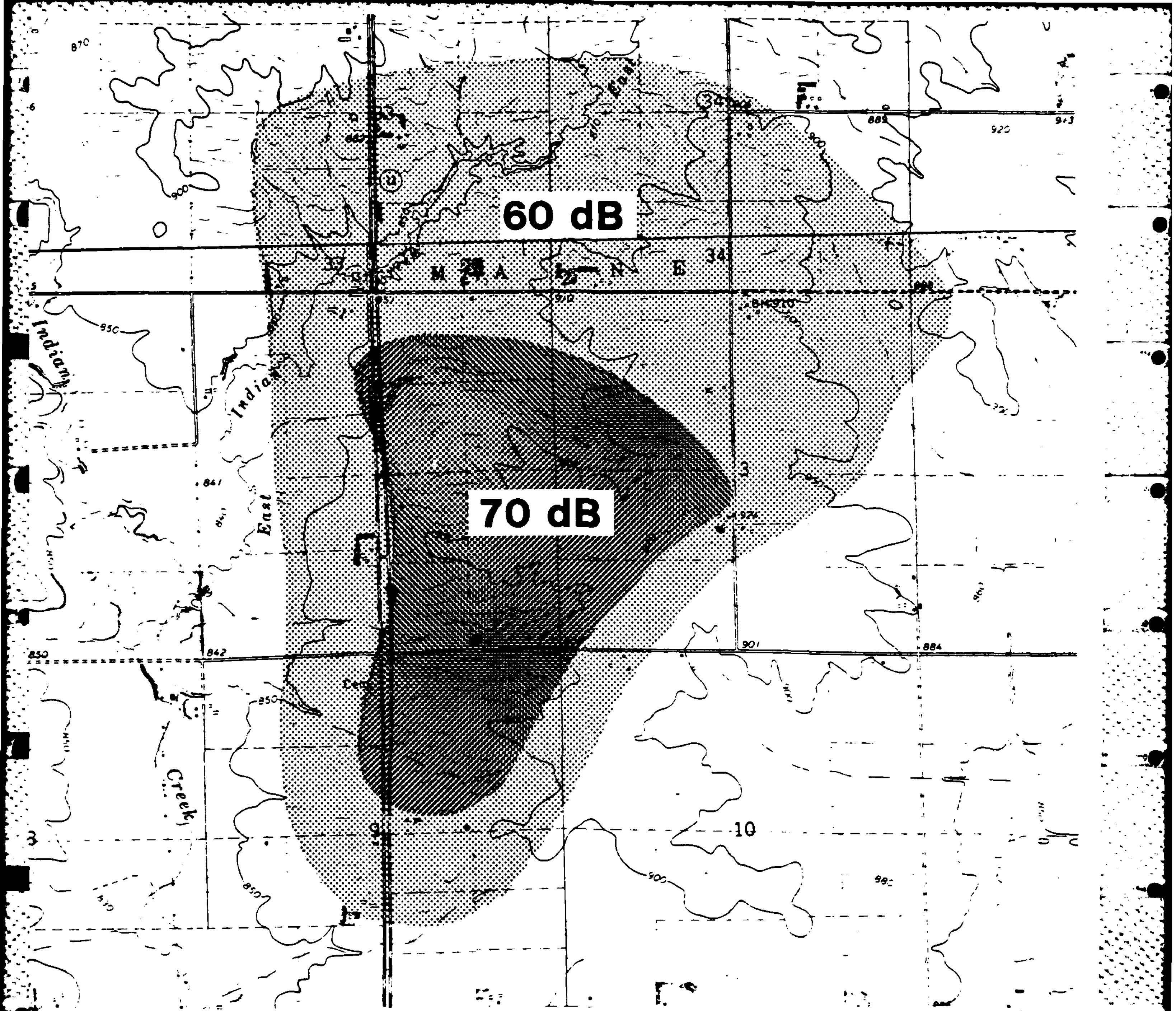
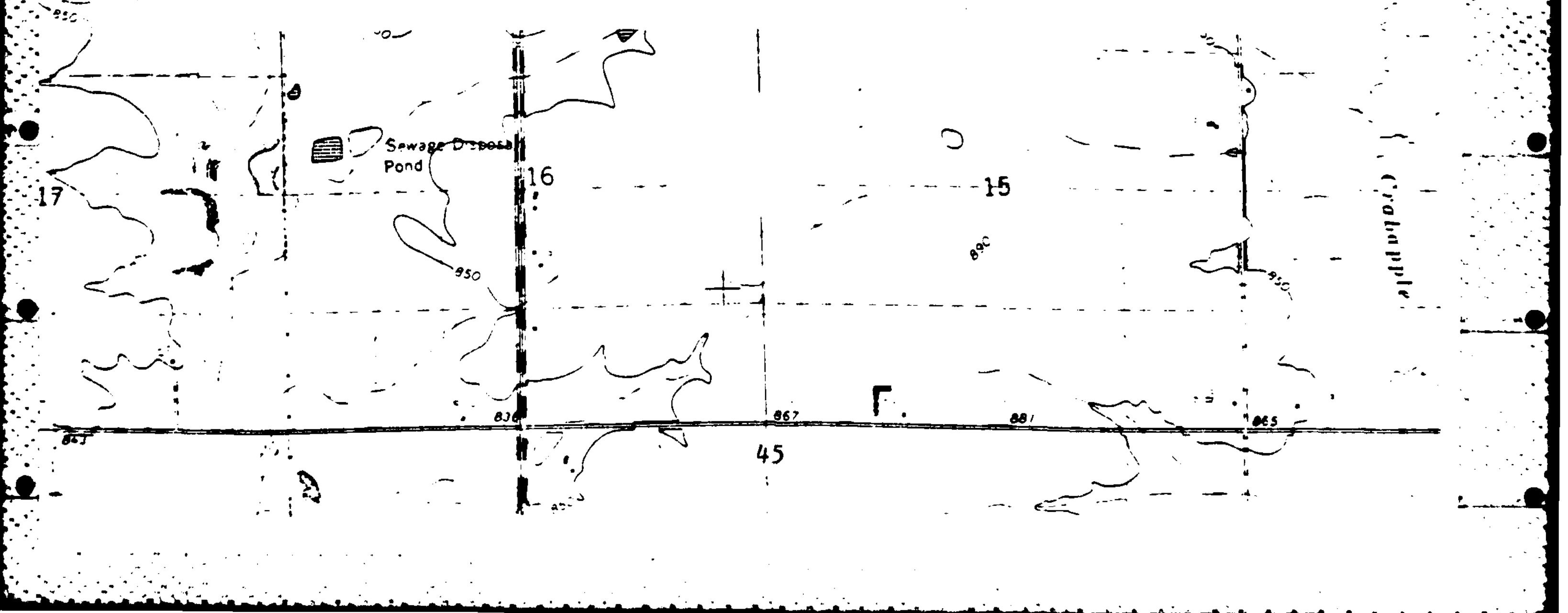


FIGURE 4.9. 125 dBC FLAT DIRECTIONAL COVERAGE



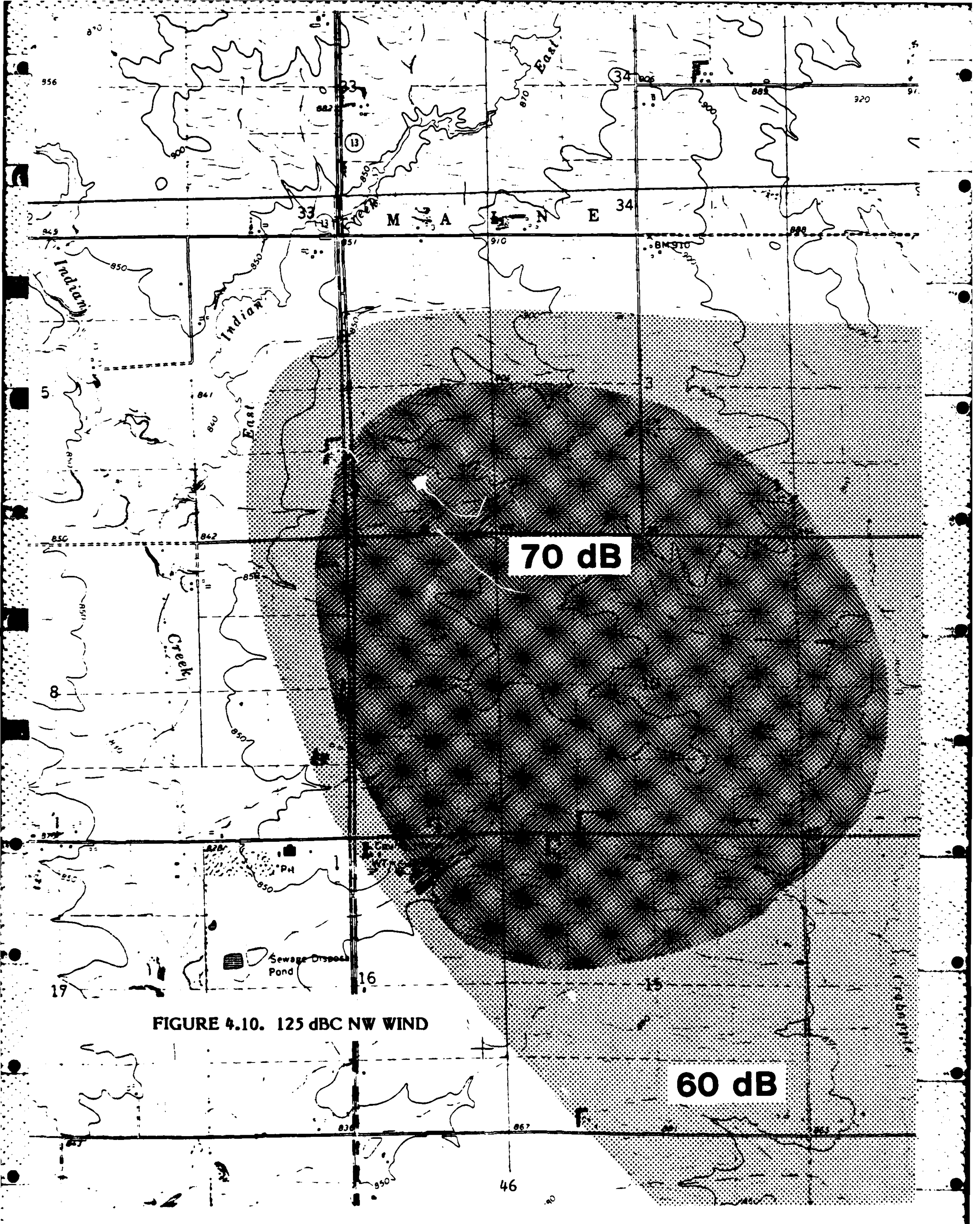


FIGURE 4.10. 125 dBC NW WIND

areas, the sound coverage pattern would be similar to a circle. When wind is introduced from one direction, this pattern, similar to that shown in Figure 4.10, will change. Other factors such as weather conditions and how they affect the sound coverage pattern are explained in the following pargraphs.

To simplify topographic conditions, assume that the sound pattern is nearly line of sight from the siren source. This allows the shadow areas of the sound coverage pattern to be identified. Each shadow area must then be examined to determine whether or not enough sound reflecting from surrounding surfaces will "fill" the shadow area.

Other shadow areas can be created by mounting a siren too high over the surrounding area. This applies when a siren is placed on a mountain more than several hundred feet higher than the surrounding area. The effect could be to create a shadow area near the siren while areas farther away receive a higher sound power level. This is caused by the fact that sirens output their sound mostly in a straight line with a sound beam width of approximately 25 to 35 degrees. Areas near the high siren inside this beam width will not get the same sound level as areas within this width. Other shadow areas are created by the atmospheric affects that are discussed in the following paragraph.

<u>4.06.03 Weather Conditions</u>

Wind and temperature difference in the atmosphere are the main components that affect the propagation of sound waves. A detailed discussion of these conditions is given in several documents (see References 12, 19, 30, 31, 35) and will not be repeated here. However, some "rules of thumb" that can be assumed from these documents are as follows:

- Wind can cause an acoustic shadow zone upwind from a sound source but can have an additive effect downwind (see Figure 4.11).

- Temperature most often decreases with height in the daytime and tends to bend sound waves upward. This can create shadow zones(34) away from a sound source (see Figure 4.11).

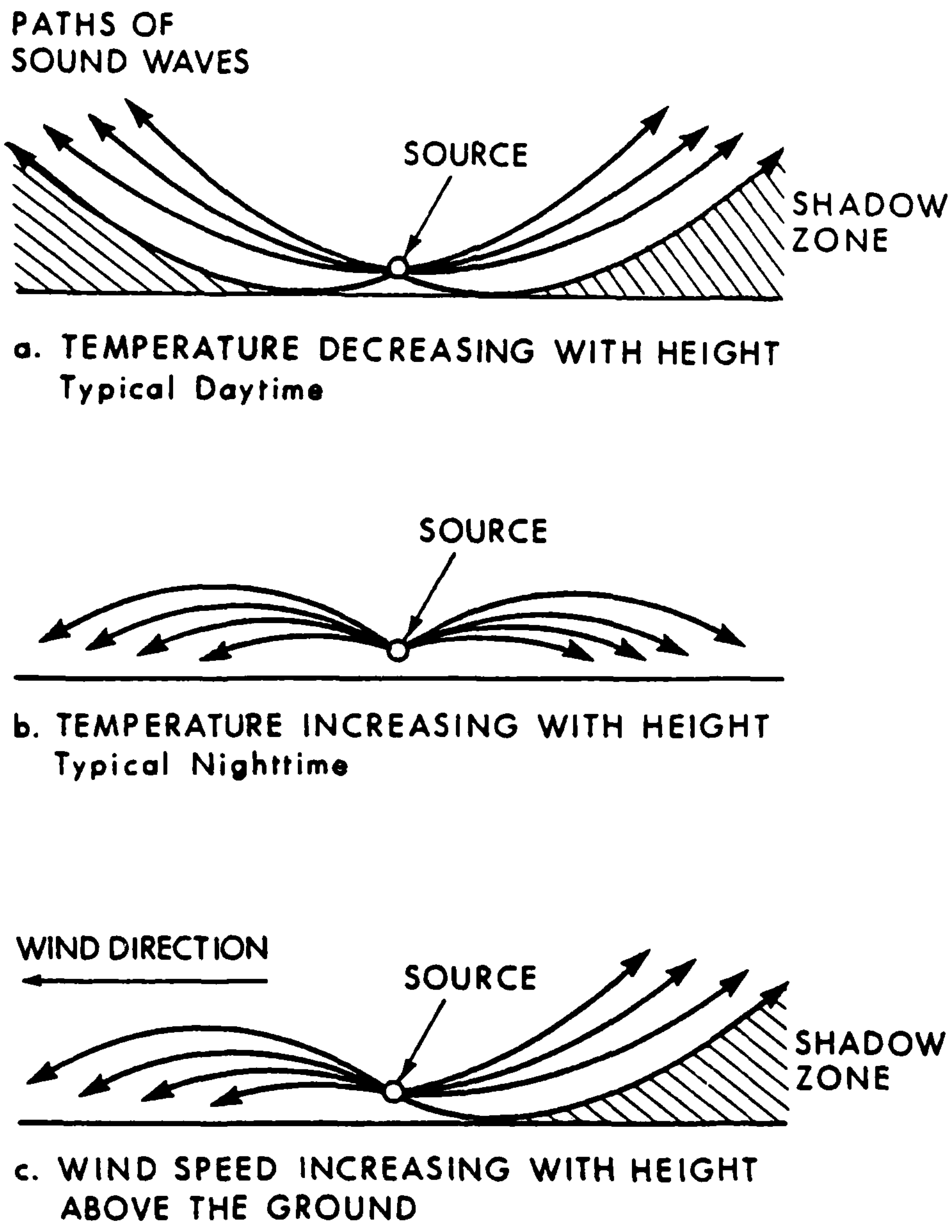


Figure 4-11. Sketches Illustrating the Effects of Vertical Temperature and Wind Gradients in Forming Acoustic Shadow Zones. (34)

- Temperatures can increase with height (nighttime) and tend to bend sound waves toward the ground.

How typical winds affect the sound patterns of a siren is shown in Figures 4.9 and 4.10. Note that for practical siren warning system designs, it is impossible to consider the various temperature conditions. However, the prevailing wind pattern should be considered since wind rose data are usually available from the local weather service offices.

Other conditions such as rain, snow, sleet, etc., all have adverse effects on sound propagation. For most of these conditions, the existing criteria for sound propagation and alerting is probably adequate, since a certain amount of tolerance is included in such criteria. When these conditions are accompanied by strong winds, however, it is extremely difficult to predict sound propagation patterns and their effectiveness.

4.06.04 Siren Control Communications

All siren warning systems require some method of activation. This can be done either by activation from a local switch, pushbutton, etc.; by indirect land lines, which can be telephone lines or privately owned cable; or by radio activation. In either case, these systems form a type of communications system from the person activating the system to the point where the sirens are activated. Direct activation is not common, except when single sirens are used, generally for fire department use or other single-purpose needs. Land lines, especially dedicated telephone lines, and radio activation are the most commonly used methods.

When telephone lines are used, usually a dedicated line is leased from the telephone company. This normally would ensure that if an overload condition of the telephone system occurs, this would not affect the dedicated lines. At each siren site, a receiving communications device is installed, which in turn activates the siren when the proper signal is received. This signal can vary greatly and system activation may be as simple as dialing one telephone number. Such a system could be expanded where additional codes are added that not only activate the siren, but

could select various siren conditions, length of activation, etc. One major disadvantage of dedicated telephone line systems is that a monthly rental fee is required and, depending upon the size of the system, may be more expensive in the long term than the cost of a radio-activated system.

Radio-activated systems are often used when a system covers a large area, such as a 10-mile EPZ, an entire county, etc. In most cases, a single frequency is used that is assigned to the local police, fire department, or local government. These frequencies are usually in the low band (30 MHz), high band (155 MHz), or UHF band (450 MHz) ranges. (The frequencies listed here are typical.) This also implies that the radio receivers used for such systems are very similar to those in use. Therefore, they do not require any special design, are readily available, and are priced competitively.

In operation, an encoder is added to the system at the base transmitter. The encoder's function is to modulate the transmitter with a combination of tones, bits, etc., which form an address and command to the radio receiver at each siren. The radio receiver is a decoder which, when it detects its preassigned address, will take an action dictated by the command sent (turn on siren, etc.). The length of time necessary for the transmitter to send such commands is very short—typically less than one or two seconds are needed, which does not interfere with normal operation. This is one of the major reasons that existing operational radio frequencies can be used for warning systems. Some of the advantages that radio communication systems have over telephone or leased lines is the lower annual operating cost and a greater flexibility when systems are expanded, changed, or updated.

Both systems, however, are subject to causing false activation of one siren or the entire system. How this happens depends upon many variables. Telephone and leased line systems can experience false activation caused by various problems that can occur at the telephone exchange. Radio signals, depending upon the level of encoding/decoding parameters, can falsely activate a siren from extraneous radio sources. Both systems are subject to false activation from lightning near the sirens

or when lightning induces voltages onto the supply voltage lines. In either case, proper shielding at the siren, good electrical grounding practices, and reliable encoder/decoder electronics are most important when integrating a communications system for activation of a siren warning system.

4.06.05 Human Factors and Training

The skills necessary for control and activation of a warning system are similar to those of a dispatcher. In fact, in most cases, the controls for warning systems are located in the dispatch office of local police or fire departments, or at the control centers of emergency services organizations. These warning systems, however, cannot be operated at any time. Obviously, it would be improper for an operator of a warning system to casually try operating all the switches and controls associated with that system as a means of learning the system. Therefore, the instructions for system operation must be so well defined that a trained person can easily read them and activate the system properly and with confidence, even the first time that the operator uses the system. Also, thorough training of this person is necessary to understand system operation. Since there is no day-to-day operation of the system, it is only natural for the operator to be unsure of his skills when needed. Not surprisingly, in those areas where warning systems are tested at least monthly, the skill level of the operators is higher than for those systems tested less often.

Another problem associated with siren warning systems is that there is no means by which an operator can be alerted if the system has been activated, unless the operator is within hearing range of the system. This is further complicated since, in most cases, dispatch and control centers are usually heavily constructed and seldom exposed to typical outside sounds. Compared to other types of communication systems, a warning system is one of the few that has no positive assurance that all aspects of the system are functioning properly. This condition tends to make a poorly trained person unsure of his actions, which might cause other improper actions. These conditions have occurred during test conditions when no real life-threatening conditions exist. Since warning systems are generally used in

life- and property-threatening situations, it is essential that skilled and trained personnel be used and that instructions for system use be clearly, easily, and quickly understood.

4.06.06 Testing

Siren warning systems must be tested for two major reasons.

- First, to test the system hardware to ensure that all parts are functioning properly and to exercise the hardware to help prevent malfunctions
- Second, the general population should be made aware of the system and be able to recognize the siren sound and its meaning

Hardware Testing — Siren systems are of many types — some are electromechanical, some electronic, others rotate or are a combination of various types. Most of these sirens are controlled by some form of communication. Most parts of the siren system are installed outdoors and, therefore, exposed to various outside elements. As a consequence, the electrical, electronic, and electromechanical parts will experience extremes in temperature and humidity. These extremes are among the major factors that cause equipment failure.

Problems can be caused by the fact that most of the controls for these units are housed in some type of metal or fiberglass enclosure. In the summer, these enclosures act as heat traps and temperatures inside can be as much as 60° F higher than the outside air temperature. This means that the electrical and electronic controls must be able to function properly at temperatures well above 150° F. In winter, the temperature extremes can also be severe. Some areas might have temperatures ranging between 40° F and 50° F below zero. However, in these cases, usually the temperature of electronic components (such as radio receivers) are warmer since they generate their own heat from being turned on. However, this is not the case for electrical relays, motor windings, etc., and these components must be able to operate at these extreme temperatures.

Temperature problems also affect rotating components since they usually have some type of bearing or rotating components that require lubrication. This means that the lubricating oils or grease must not become too heavy in cold weather nor too light in hot weather. Also, these gears and components will naturally lose their lubrication over time if not used, since the lubricants will eventually settle. It is a good engineering practice to occasionally exercise such systems to prevent this type of occurrence. Note that these are but a few examples of the type of problems that can occur with a siren warning system. By periodic testing, failures would be detected, operators would receive valuable training, and some type of failures could be prevented.

The second reason for periodic testing—community awareness—is to educate the general population about the system. This document does not discuss the reasons for such testing, but recognizes that it is extremely important to make people aware of the purpose of the warning system.

4.07 MOBILE SIRENS – TECHNICAL SPECIFICATIONS

Mobile sirens form a part of many warning systems; especially those that cover rural areas where fixed sirens are not cost-effective. Most often, these mobile sirens are police and fire vehicles. They differ from fixed sirens in that mobile siren output levels are not nearly as high as fixed siren sounds and that the output sounds vary depending upon the make and model number.

The sound output levels for typical mobile sirens range between 90 to 117 dBA at 12 feet. Fixed sirens are rated on the dBC scale at 100 feet. These mobile sirens, therefore, have a much smaller range, which depends mostly on the speed of the vehicle. Most of the factors that affect fixed siren sound propagation do not apply to mobile sirens. This is mainly due to the limited range expected of the mobile siren at which such factors as rain, topography, and background noise do not affect sound propagation as greatly. The main purpose of mobile sirens is to alert people in areas next to roadways on which they travel. This means that the area coverage of a mobile siren at a particular moment would be only a few hundred feet or less

which is the typical distance from roads to houses. At this distance, the acoustic energy from a mobile siren does not decay at the rates assumed for fixed sirens (average 10 dB loss per distance doubled). This energy is affected mostly from hemispherical divergence and atmospheric absorption; and, in comparison, the affects of spreading and other topographical conditions are minor. The net result is that mobile sounds decay closer to 6 dB per distance doubled for the comparatively short range at which the signal can be effective.

This is easily seen by noting that a typical mobile siren with an output of 115 dBA at 12 feet would have propagation losses similar to those shown in Table 4.7. Notice in this table that examples of signal loss are shown for 5, 6, 7, and 8 dB starting at a distance of 12 feet.

TABLE 4.7. MOBILE SIREN SOUND PROPAGATION LOSSES FOR DISTANCE DOUBLED FOR dB LOSS BETWEEN 5 to 8 dB

Distance (Feet)	Typical Mobile Siren Output	Various Acoustic Energy Losses For Doubling of Distances: 5 dB	6 dB	7 dB	8 dB
12	115 dBA	115	115	115	115
24		110	109	108	107
48		105	103	101	99
96		100	97	94	91
192		95	91	87	83
384		90	85	80	75
* 768		85	79	73	67

* As distances go beyond this nominal range (600 to 1,000 feet), other factors affect sound propagation similar to those for fixed sirens and, therefore, the energy losses per distance doubled would be greater.

Using the above table, and based upon other studies(15), the expected warning range for mobile sirens would typically be 500 feet for getting the attention of someone indoors. This, of course, depends on many factors (such as type of building construction and perception of the signal) but, more importantly, on the amount of time for which the siren signal will be heard.

The output frequencies of most mobile sirens are in the 500 to 3,000 Hz range, which, on average, is higher than fixed siren frequencies. There are many higher harmonics produced by these sirens, especially when the wail, yelp, and hi-low sounds are employed. These have an effective attention-getting affect, but are not standardized for emergencies.

Another factor in determining mobile siren range is the output pattern of the sound. In most cases, the output sound pattern is oval(14) shaped with more power directed toward the front of the vehicle. This is shown in Figure 4.12. Notice that the sound coverage does not extend as far toward the sides and rear of the car. This indicates that the warning effectiveness is reduced at the sides of the vehicle. This also puts more emphasis on the fact that the vehicle should be pointed toward the area to be warned for maximum effectiveness. This must be considered when using Table 4.7 for coverage estimates.

There are two kinds of mobile sirens, electromechanical and electronic. About twice as many police departments use the electronic sirens, although as sirens are replaced, most are replaced with electronic sirens(40). Both types of sirens are mounted on top of the vehicle, behind the grill, or in the engine compartment. Most electromechanical sirens are mounted behind the grill or in the engine compartment, however, while approximately 70 percent of the electronic sirens are roof-mounted.

When these sirens are used for warning, often the public address capability is also used. Nationwide, approximately 60 percent of the police departments have this capability, allowing the emergency vehicle to not only warn, but also provide information necessary for immediate action. These public address systems do not have the same output power range as the siren. However, usually emergency vehicles travel slowly when using this capability, making public address capabilities an effective part of any warning system.

In addition, most emergency vehicles have roof-mounted warning lights that are generally used whenever the siren is activated, and also act as effective short-range warning devices at night.

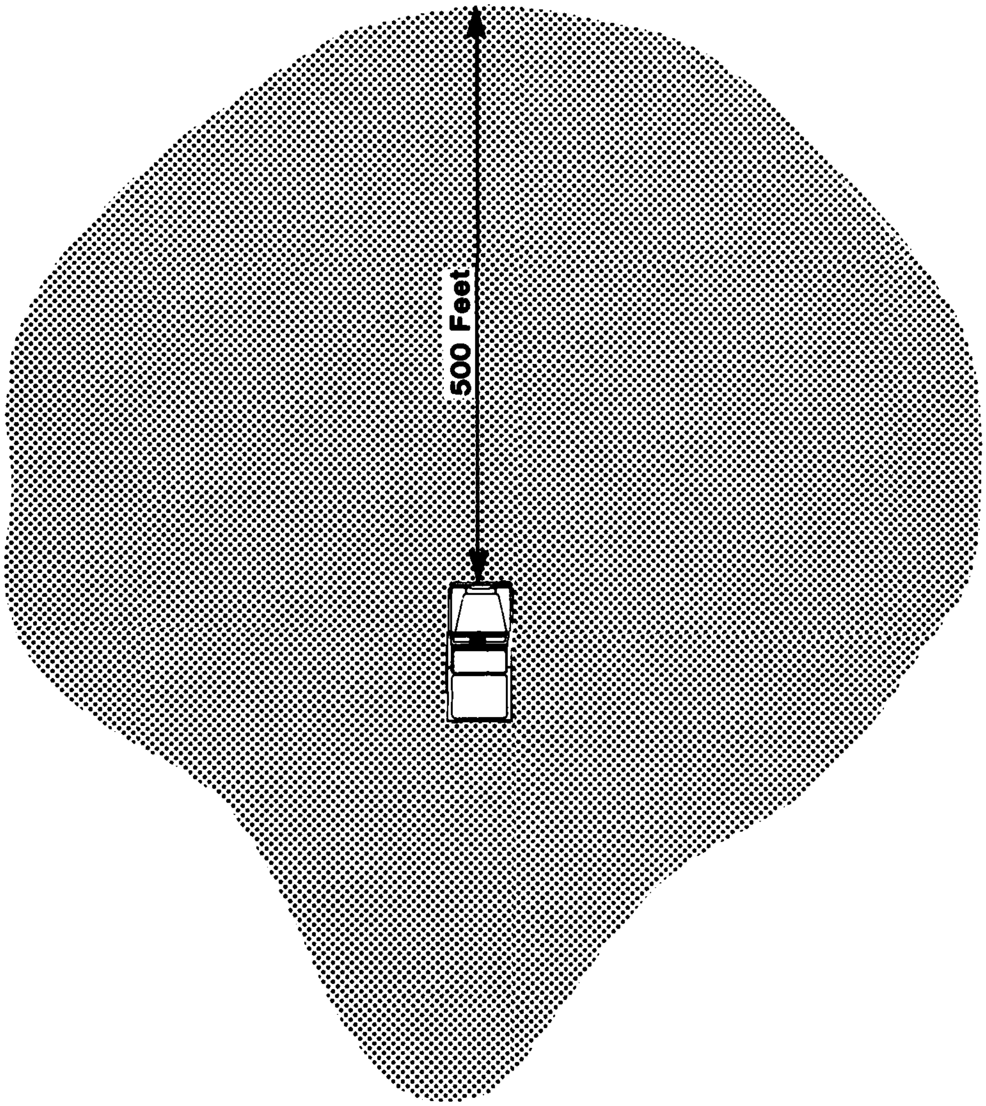


Figure 4-12. Emergency Vehicle Typical Sound Output Pattern

In practice, mobile sirens are effective for warning because of the time period for hearing the mobile siren in warning situations is usually much longer than for all other emergency vehicle type situations. This applies even though the mobile siren sound is not standardized similar to fixed sirens. Also, since mobile siren ranges are short, the criteria affecting sound propagation at long ranges rarely applies. the major factor affecting mobile siren effectiveness is usually the speed at which the vehicle travels and the road conditions.

The slower a mobile siren travels, the more effective the perception of an emergency will be. On the other hand, this limits the coverage area of a mobile siren and, therefore, the number of people that can be warned in a reasonable time. Also, traffic congestion caused by severe weather conditions such as ice or snow could obviously impede mobile sirens from covering an area in a specified time period.

4.08 TELEPHONE SWITCHING/DIALERS

4.08.01 Small-Scale Applications

Telephone systems, as a means of mass warning, have applications in selected situations; these might include mass alerting via telephone in apartment buildings, motels, hospitals, etc. Since buildings such as those mentioned are, effectively, small telephone exchanges, using the phone system for warning applications is easily accomplished.

Generally, there is a limited number of phone lines (trunks) coming in to a large building. These lines enable a certain percentage of telephones to be used at one time for incoming and outgoing calls. This percentage may vary between 15 to 40 percent or more, depending upon usage. A switching network of some type exists between the individual telephones and the trunk lines entering the building. At this point, if additional switching equipment were installed, all of the telephones within the building could be accessed simultaneously, since a hardwire line would exist to each telephone from the switching equipment.

There are many variations, however, which may limit the number of telephones that could be called at any one time. In any case, the equipment is available but is usually more expensive than, for example, a system of warning bells installed at central locations.

4.08.02 Large-Scale Applications

Note that the telephone applications would be extremely expensive to apply on an areawide basis and would require a careful engineering design to ensure that all telephones are accounted for. This necessitates in-depth knowledge of the local telephone exchange and would require very close cooperation with the local telephone company. Also, the system would only be able to simultaneously call as many telephones as the system can usually accommodate (for areawide telephone systems this is generally only 15 to 30 percent of all customers at one time). Therefore, the first calling sequence of approximately 15 percent of the subscribers would be followed by a calling sequence of the next 15 percent. To completely call all telephones might require 5 to 10 different calling sequences. Based upon these data, automatic switching units for mass warning via telephone have limited applications.

In addition, such systems often use a prerecorded message. This means that a person answering a telephone might pick up somewhere in the middle of the message and would, therefore, require that the message be given twice. This would have to be automatic and would lengthen the time required to alert.

However, this system could be designed to simply give a distinctive ring without a message. The ring might then have the same meaning and effectiveness as a siren. In fact, years ago, older telephone systems could control special rings by operators and used such methods to warn of tornadoes or for other emergencies. Since local exchange operators have been replaced by automatic switching units, this capability can only be implemented with special equipment.

4.09 POWER LINE DEVICES

Power line devices are briefly discussed in Chapters 2 and 5. Currently only one system of this type is in existence and little data is available.

5. GENERAL WARNING SYSTEM GUIDELINES AND EVALUATION PROCEDURES AND COSTS

This section contains the procedures for evaluating warning systems. It is presented in the form of general guidelines and includes a list of the specifications that should be used to compare different warning system components.

The guidelines are intended to allow a person with minimum technical qualifications to evaluate a warning system. From this evaluation, it is expected that an assessment can be made by comparing the system to some other criteria. Specifically, these guidelines can easily be applied to the criteria stated in NUREG 0654, Rev. 1, Appendix 3. They can also be applied to other systems to give a qualitative overview of any general warning system.

These guideline and evaluation procedures are based upon information obtained from a variety of sources. These sources include the design methods used by various manufacturers and consulting firms; designs of existing old and new systems; factors concerning communication, control, and acoustical sound propagation; equipment hardware and power distribution systems design; and research and tests performed under this contract. In addition, conversations with warning system operators, equipment manufacturers, installers, communications specialists, and a variety of other experts were also considered.

The evaluation procedure and guidelines are divided into several categories. These include overall system guidelines, and guidelines for fixed sirens, mobile sirens, tone alert radios, telephone switching/dialing equipment, power line devices, and control methods (radio or leased lines).

5.01 OVERALL WARNING SYSTEM EVALUATION GUIDELINES

To assess a warning system, in general, proceed as follows:

a. Determine the area that the system is intended to cover and then obtain a map that details all roads, dwellings, rivers, lakes, and other

topographical conditions. This can be obtained from the U.S. Geological Survey at a nominal cost.

b. Determine the type of systems used for warning and proceed to the following sections that deal with each type of system.

5.02 FIXED SIRENS

Using the map described in the previous paragraph, proceed as follows:

a. Plot each siren location on the map and indicate, next to each siren, the rated output power level

b. Determine what the measured or estimated background noise level is for the entire area. Use the figures and tables in Section 4 to help in this determination. Consider the following:

- Hypothetically, in a 10-mile radius EPZ, fairly flat rural environment, where the average background noise level never exceeds 50 dBA, approximately 30 sirens, rated at 125 dBC are required for full siren sound coverage.
- A siren sound level should be 10 dB above the background noise to alert someone who is preoccupied. The key word is alert. Note that a person can hear a sound even when it is below the background noise, but only if they are listening for that sound.
- Background noise levels should be taken using the dBA scale.
- Most background noise is generated by automotive traffic. Therefore, usually more sirens are required near busy highways than in suburban or rural areas.
- Typically, siren systems in a 10-mile radius EPZ do not use only one type of siren. Smaller sirens are often placed in areas where limited coverage is dictated by surrounding hills, valleys, mountains, etc. Many of these systems may have between 45 and 90 sirens of several types for full siren sound coverage.

c. Determine the exact make and model number of the siren and whether it is an electromechanical or electronic siren. From the manufacturer's literature, determine the output power rating in dBC at 100 feet. From this information, determine the range of each siren based upon the figures and tables in Section 4 and plot these ranges on the map, considering the following:

- Sirens should be compared after output power has been measured at 100 feet on the dBC scale. Do not use ground effects or other measurements when comparing sirens.

- Electromechanical sirens operate from supplied AC voltages. These sirens cannot be operated from batteries since the amount of power required greatly exceeds what typical batteries can supply. Therefore, if that siren is electromechanical, ensure that enough AC power is available for the siren to operate at full rated power.

- A typical back-up power supply for a 123 to 125 dBC rated electromechanical siren would have to be a large motor generator capable of supplying several hundred amps continuous AC power. A a result, few if any of these sirens have back-up power.

- Electronic sirens operate from two 12-volt batteries (truck size capacity), not from supplied AC voltage. They, therefore, automatically have back-up power.

- Electronic sirens require 115 VAC to keep the batteries at full charge.

- Thirty minutes is the maximum operating time for electronic sirens to operate at full rated output power at 50° to 70°F, starting from a full battery charge.

- Temperatures near or below freezing (down to -30°F) will reduce the maximum operating time of electronic sirens by as much as 6 to 10 minutes from the nominal 30 minutes operating time.

- Only electronic sirens are capable of voice broadcast as well as tonal signals.

d. Determine from the manufacturers' literature the output frequency of the siren. This can affect sirens that are intended for indoor warning as well as outdoor warning. Consider the following:

- Commercially available fixed sirens range in output frequency from 387 Hertz up to 1,275 Hertz.

- Generally, the lower siren frequencies are attenuated less than the higher siren frequencies from outside to inside in a typical wood-frame home.

e. Determine from the original design whether or not the siren output rating purchased agrees with this original design. Review the tables

in Section 4 to determine the difference in sound coverage for a small dB change in output power. Consider the following:

- A 5 dB loss in siren sound output translates to half the area coverage.

f. Determine whether a testing and preventive maintenance program is standard operational procedure. Consider the following:

- Sirens should be tested monthly to verify operation. Preventive maintenance procedures recommended by the manufacturers should be followed.

- When tests are performed, determine if operators have been trained prior to operation and whether this training is adequate to ensure reliable operation.

g. Determine system cost effectiveness. Consider the following:

- In many cases, the most cost-effective sirens are the ones rated between 123 to 125 dBC rotating directional. These are also the most widely used since they can be operated from single-phase or 3-phase power, and their coverage area is greater than most other sirens.

- A typical 123 to 125 dBC rated siren mounted on a pole, with radio controls, averages $12,000 to $13,000 installed, for systems over 30 units.

- Siren systems of 30 sirens mounted on poles may range in price from $375,000 to $550,000 including installation, mounting, and control equipment.

h. Determine the method of siren activation. If radio activated, consider the sophistication of encoders and decoders used and whether or not they may be prone to false activation by other radio signals. Consider the following:

- The greater the number of tones or bits required for activation, generally the less susceptible a system is to false radio activation.

i. Determine if the best procedures have been used for installation to prevent false activation from sources such as lightning or line surges.

- Generally, steel conduit for control wire on a pole-mounted siren helps to prevent false activation from electrical interference.

- All siren systems should be well grounded at the pole using approved grounding methods.

5.03 MOBILE SIRENS

When mobile sirens are to be used in a warning system, determine the number of mobile units that would be available for warning purposes. To determine coverage area of a mobile system, proceed as follows:

a. A mobile unit must travel very slowly for people to recognize the siren as having a meaning other than an emergency vehicle passing. On this basis, assume that a mobile unit might travel at 5 mph. Consider the following:

- A mobile siren unit travelling at 5 mph covers 1¼ road miles in 15 minutes; at 10 mph, 2½ road miles are covered.

- The effectiveness of mobile sirens for warning may depend upon public address capability of the vehicle.

- Assume that a mobile siren's most effective warning range is within 500 feet of where the vehicle travels.

b. Add up the number of linear road miles that mobile sirens must travel and divide by 1.5. This will yield the approximate number of vehicles required for warning within 20 minutes.

c. Determine how drivers are made available for operating mobile sirens. From this determine the average amount of time each driver would need to be in position. Add this time to the 20 minutes given in Step b. above to determine the total average time for warning.

Note that since mobile siren warning distances are relatively short, the output power rating of the mobile siren has less bearing on coverage range than do other factors. These factors include vehicle speed, the distance of dwellings from roadways, and the type of construction of the buildings.

5.04 TONE ALERT RADIOS

Evaluation of the effectiveness of a tone alert radio warning system is mostly dependent on the output power of the transmitter. In the case where a tone alert system uses NOAA radio or some other commercial service (such as pager systems), these systems can usually provide information regarding their effective range. Typically, commercial paging systems cover a radius approximately

50 miles from a transmitter. Such systems, however, may have more than one transmitter, thereby increasing their range. NOAA radio coverage areas vary; however, they can be compared to the coverage ranges of some commercial radio stations which typically range from 20 to 100 miles radius.

Coverage areas for tone alert systems using local police or fire transmitters range from 20 to 40 miles radius.

Therefore, it is best to consult the communications director of an organization to determine the effective coverage of such a system. Assuming a police transmitter is used for tone alert with a nominal 30-mile radius coverage, simply plot a 30-mile circle from the point where the transmitter is located. If this covers the area to be warned, then other obstacles to be considered are usually mountainous areas and valleys. Such areas, in many cases, cause radio coverage "dead spots." Usually these areas are well known to the communicators in charge, who are the best source for determining effective coverage.

Of course, the quality of the tone alert radio receiver will have some affect on coverage. This affect, however, can only be determined on an individual basis. This information is available from each specific radio manufacturer.

5.05 TELEPHONE SWITCHING EQUIPMENT

Telephone systems, to this date, have not been used as part of a warning system. Telephones, however, are used extensively to tie together major control centers. Such communications usually rely on telephone lines leased from the phone company and cannot be affected by public overload of the commercial phone system. These systems are often referred to as hot lines, ring-down lines, or dedicated lines. In many cases, one station need only to lift the receiver, which then automatically rings other phones on the lines. Such systems are usually limited to three or four parties to a line, although this does vary from one system to another. In any case, telephone equipment for emergency warning of the general public has potential application in high rise buildings, offices, etc.

However, since no general warning system of this type has been found, it may be concluded that costs and other factors, at this time, prevent such systems from being used for general warning.

5.06 POWER LINE DEVICES

Power line devices are currently installed as warning devices in only one location. Approximately 1,400 units are to be installed at homes near the Duquesne Light Company, Beaver Valley Power Station in Shippingport, Pennsylvania that are not easily covered by fixed sirens. Each unit is attached with the power meter where main power enters a house. A small siren is a part of this unit.

This type of system is controlled by computer from a location at the Duquesne Light Company facility. The control signals are sent over the power distribution network. Two hundred of these units have two-way capability. This allows for positive testing and verification. Of these 1,400 units, 1,200 are equipped with a light, in addition to a small siren, that is activated when tested and verified when the meter is read. The light is used as a means for determining activation.

Since this system is the first of its kind, evaluation procedures and guidelines are confined to verification results during testing. Reports indicate that the unit operates as an outdoor warning device in the nearby area as well as an indoor warning device.

5.07 COSTING

The cost of a warning system includes many components that comprise a system. For a complete warning system using only fixed sirens that are radio activiated, the major costs include:

- Sirens
- Radio communication/decoders
- Radio control encoders
- Installation (assume pole-mounted)

- Initial spare parts
- Training
- Maintenance agreement

Other items required for a warning system are often already in place and, therefore, are seldom considered in the overall system costs. These include:

- Control centers and those items necessary to equip such facilities
- Radio transmitter or telephone leased lines
- Radio towers
- Communications links to control centers and responsible officials
- Annual maintenance costs
- Personnel costs

Systems that use other types of warning devices, such as tone alert radios, mobile sirens, etc., would include the costs for these units. However, in most cases, mobile sirens serve more than one function and are generally not included in overall warning system costs. Nevertheless, where new mobile sirens are purchased strictly for warning purposes, obviously, these costs would be considered. Tone alert radios, telephone calling units, and power line modulation devices are the other major items that can add to the cost of a warning system.

Table 5.1 gives typical unit costs for commonly used sirens.

TABLE 5.1. TYPICAL SIREN TYPES AND COSTS (UNIT PRICES)

Siren Type	Unit Cost Range
101 dBC Omni-Directional Electromechanical; Single-Phase and 3-Phase	$ 2,000 to $ 2,200
105 dBC Omni-Directional Electromechanical; Single-Phase and 3-Phase	2,400 to 3,950
110 dBC Omni-Directional Electromechanical; Single-Phase and 3-Phase	3,400 to 5,200
115 dBC Omni-Directional Electromechanical; Single-Phase and 3-Phase	4,600 to 5,400
115 dBC Omni-Directional Electronic Siren with Public Address	5,300 to 7,500
120 to 122 dBC Omni-Directional Electromechanical; Single-Phase and 3-Phase	4,600 to 7,400
123 to 126 dBC Directional Electromechanical; Single-Phase and 3-Phase	8,000 to 9,000
123 to 126 dBC Directional Electronic Siren with Public Address	9,000 to 10,000
123 to 126 dBC Omni-Directional Electromechanical; 3-Phase Only	9,500 to 10,500
135 dBC Directional Electromechanical; 3-Phase Only	14,500 to 16,000

Note that there are other costs incurred when purchasing sirens. Additional charges include such items as mounting hardware, special controls, etc., which may or may not be incluced in the price of the siren. Radio controls are not listed in the above prices. Those vary from $500 to $1,000 for the receiver decoder installed at the siren. This cost depends on the number of features each unit has as well as the level of complexity of the decoder.

Also, final siren unit prices may be lower, depending upon discounts received for quantity purchases. However, when installation costs are added (including

materials and labor), the final cost is usually higher than the siren unit cost multiplied by the number of sirens purchased. Typically, a 45-siren installation of 125 dBC rated sirens, including radio encoders and decoders and all installation costs, may range from \$500,000 to \$750,000. This does not include spare parts costs and may or may not include maintenance and training.

In addition, often the major consideration in installing sirens is power availability. This applies when three-phase power is not available and single-phase power is not adequate to power an electromechanical siren. Note that the costs to add sufficient power can exceed the cost of the system itself. In such cases, electronic sirens are the most cost-effective, since they only require enough power to keep batteries at full charge.

APPENDIX A. TEST RESULTS – SITE VISITS AND INDEPENDENT TESTS

This appendix contains the data and summarizes the results of tests performed on six different warning systems. Other tests were performed to obtain background noise and sound propagation readings both inside and outside of homes and office buildings. Also, tests performed by others on specific sirens and at other nuclear power plant facilities were used as background data.(5,10,16,18,20,21,22,23,24,41) The test site visit schedule is contained in Table A-1.

The tests performed at the five different nuclear power plants required initial preparation. For each site visited, documents supplied to NRC describing the utility's design and implementation of each warning system, were examined. Using U.S. Geological Survey topographical maps for each site, the locations of warning system sirens and transmitters were plotted according to the plans supplied. Then, each site was visited and each siren location plotted precisely. The make and model number of each siren was determined and a survey made of each siren installation.

This site survey was used to determine the siren location and data collection positions that would yield the most useful data. One of the test objectives was to determine the output power level of a siren and then collect data from that sound source, as well as several data collection positions. In this way, the factors affecting sound propagation could be compared to a central source. For nuclear plants, usually three test positions were selected. One position aimed to obtain a precise calibration of the siren, requiring a bucket truck 100 feet from the siren with the bucket raised to the level height of the siren. The other positions were determined based upon terrain, wind, and density of vegetation. Each of these positions is described for each test.

In addition to the nuclear plant site visits, three tests were performed using the Washington Area Warning System. In each case, a house was selected. These were located 1,300 feet, 1,500 feet, and 2,400 feet, respectively, from a siren. Test positions were then selected outside and inside the house.

TABLE A-1. SITE VISITS — WARNING SYSTEM TEST LOCATIONS

Date	Test Site	Conditions
April 24, 1982	Salem Nuclear Power Plant, Salem, New Jersey	Temperature 75°F, wind average 10 to 15 miles per hour
September 18, 1982	North Anna Nuclear Power Plant, Spotsylvania County, Virginia	Temperature 65°F, wind SW Average 0 to 6 miles per hour
September 28, 1982	Calvert Cliffs Nuclear Power Plant, Calvert Cliffs, Maryland	Temperature 68°F, wind Variable 0 to 5 miles per hour
October 6, 1982	Duane Arnold Nuclear Power Plant, Palo, Iowa	Temperature 64°F, wind calm
October 13, 1982	Washington Area Warning System (WAWAS), Alexandria, Virginia	Temperature 74°F, wind calm
November 10, 1982	WAWAS, Aspen Hill, Maryland	Temperature 67°F, slight breeze
December 8, 1982	WAWAS, Falls Church, Virginia	Temperature 62°F, wind calm
December 11, 1982	Maine Yankee Nuclear Power Plant, Booth Bay Harbour, Maine	Temperature 27°F, slight breeze

For all of these tests, sound level readings were taken to measure background noise and siren sound propagation. The equipment used consisted of:

- Bruel and Kjaer (B&K) 2203 Precision Sound Level Meters
- B&K 2306 Portable Level Recorder
- B&K 4230 Sound Level Calibrator
- Morantz CD-320 Superscope Portable Cassette Deck

In all cases, the data was recorded both manually, by observation of the sound level meter, and electronically on the cassette deck or level recorder. Pre- and post-calibration checks were made for all readings. Recording of the data on cassette allowed for post-test analysis and verified readings taken by observation. This also allowed for observation of the data by other laboratory equipment to determine siren frequencies, signal power levels, and pattern changes as they occurred.

Portions of the data collected during each site test are shown in Figures A-1 through A-19. These figures highlight segments of each test, and represent approximately 10 percent of the data collected. Typical test results are shown. Nearly all of these data were recorded on high-quality cassette tape. In some cases, the time scales used in the figures vary. This is intended since some data can easily be compressed to provide a better overview of test results. In all cases, the data collection process relied upon recorded readings taken from the sound level meters. These data, which were also recorded on paper or cassette tape, were replayed later under laboratory conditions for further analysis on the chart paper with the level recorder and viewed on an oscilloscope.

Notice that in some cases the paper tape recordings were annotated during testing. No attempt was made to remove these notations, since they do not interfere with examination of the data. Also, note that when collecting data, the scale (or dB range) that is selected on the sound level meter changes depending upon the sound power level of the received signals. This change of the dB scale is shown on each graph and may differ from one test to another. Therefore, it is important that these different scales be considered when viewing the data.

A-1-1 SALEM SITE VISIT AND TEST

The Salem Nuclear Power Plant in Salem, New Jersey, has a nominal 10-mile EPZ. This includes parts of Delaware and New Jersey separated by the Delaware River. Approximately 20 percent of the area is covered by water. Most of the land area is flat (especially on the New Jersey side), with farmland and rural area comprising most of the EPZ. There are 28 sirens installed, 16 in New Jersey and 12 in Delaware, and they include two basic siren types manufactured by Alerting Communicators of America (ACA). There are eight Allertor directional sirens rated at 125 dBC and 20 Cyclones omni-directional rated at 125 dBC. All units are electromechanical sirens and are radio activated. Two separate control centers, one in Delaware and one in New Jersey, can activate the system. All sites were examined and a site near Bay View Beach in Delaware was selected for test. Only one data collection point was selected 4,000 feet east of an ACA 125 dBC Allertor siren.

The test was performed on Saturday, April 24, 1982, at 12:30 p.m. and consisted of activating the 12 sirens in Delaware from the EOC located in Delaware City. Seventeen sirens located in New Jersey were activated from the EOC in Salem. Coordination between EOC's was by regular telephone and by direct radio. All sirens were activated for three minutes followed by approximately 30 seconds off and three minutes on. Sound pressure level readings were recorded at a point just outside Bay View Beach. The background ambient noise level was between 40 and 54 dBC. The results of the test are shown in Figures A-1 and A-2.

The maximum received signal level was 79.5 dBC and varied from 71 to 79.5 dBC each time the siren pointed toward the data collection point. The siren output was not measured for calibration. Note that although the wind was blowing from west to east at 10 to 15 mph, the minimum received siren signal level rarely went below 60 dBC—even when the siren was pointed 180° from the data collection site. In effect, the stronger winds appear to have aided the sound propagation more than in other tests where the wind did not exceed 5 to 8 mph. The design of the system and siren placement were intended for greatest effect in the 5-mile radius EPZ, since most sirens were located in this area.

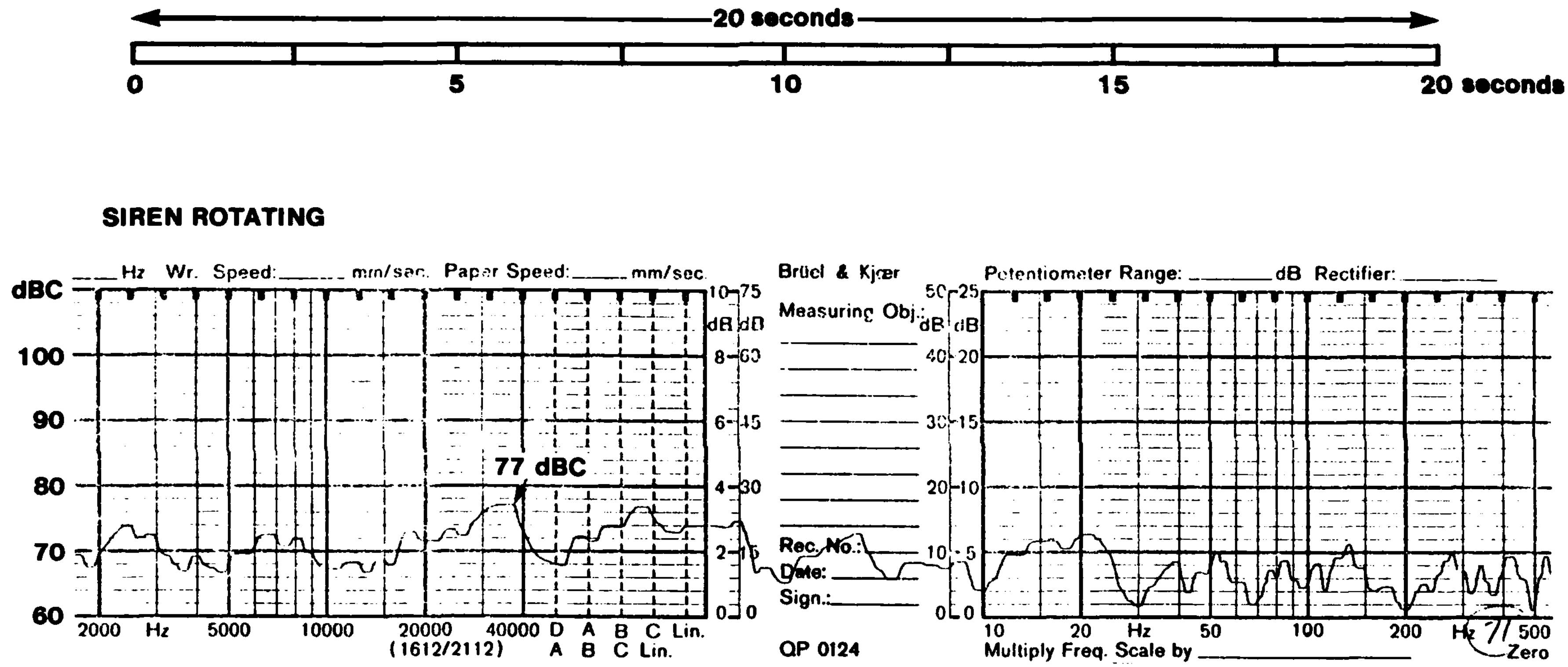


Figure A-1. Salem, N.J. Nuclear Power Plant - 125 dB ACA Allertor Electromechanical Directional Siren at 4000 Feet

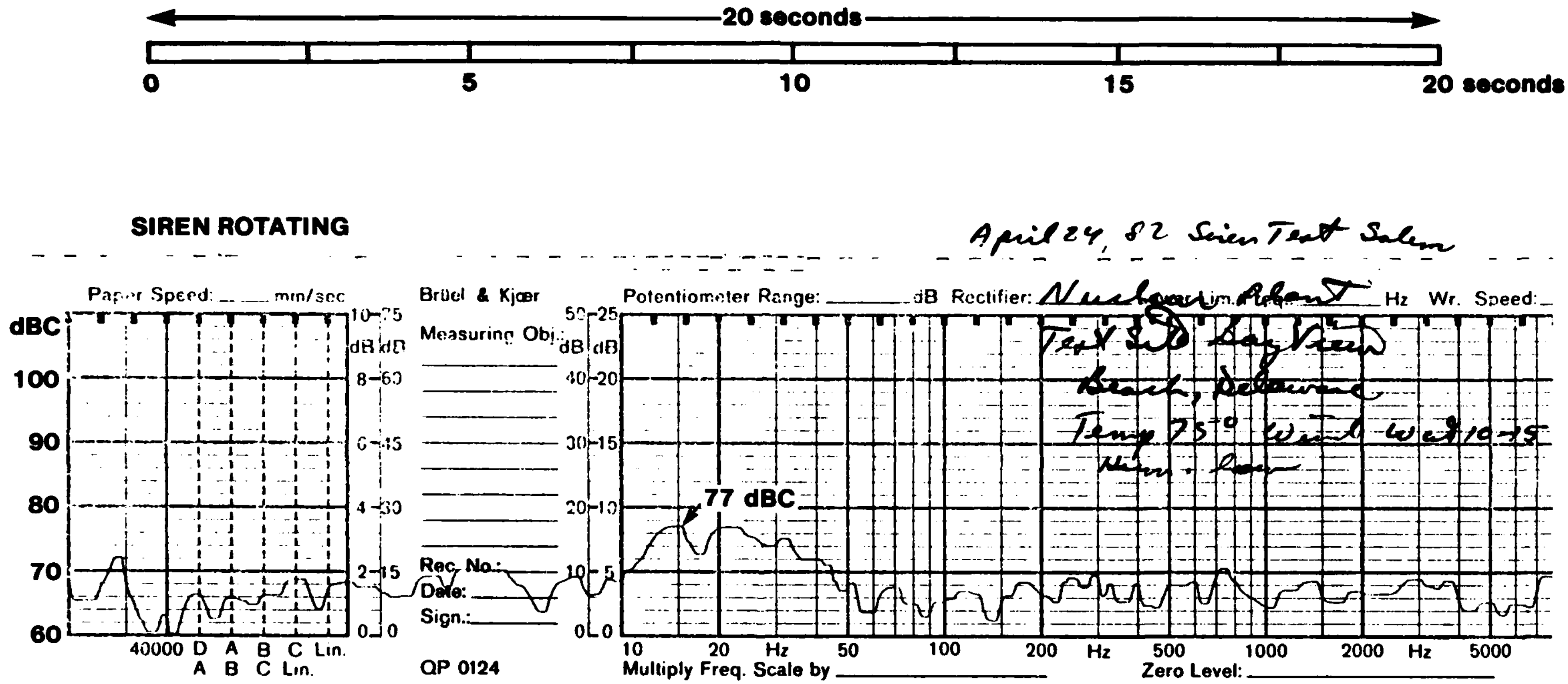


Figure A-2. Salem New Jersey Nuclear Power Plant - 125 dBC ACA Electro-mechanical Directional Allertor Siren at 4000 Feet - Maximum Reading Not Shown was 79.5dBC, Minimum 71 dBC with Siren Pointed at Test Station

A-1-2 NORTH ANNA SITE VISIT AND TEST

The North Anna Nuclear Power Plant is located on the shore of Lake Anna, approximately 30 miles southwest of Fredericksburg, Virginia. The 10-mile EPZ includes parts of five counties, is almost entirely rural, and has heavily wooded rolling hills with some farmland. In the center of the EPZ, Lake Anna covers approximately 10 to 20 percent of the land area and is used extensively for fishing and other recreational activities.

The warning system consists mainly of Sentry siren models 10V2T omni-directional electromechanical, rated at 120 to 123 dBC. All sirens are radio controlled from their respective county dispatch center.

A site for test was selected where a calibration was made 100 feet away from the signal source at siren level in a bucket truck. Two other locations were selected 5,000 feet east and west of the siren. The test results shown in Figure A-3 show that the siren output level averaged 110 dBC. Figure A-4 shows that 5,000 feet west of the siren the background noise averaged (bottom chart) 50 to 51 dBC. The measured siren level at this point averaged 55 dBC. The other location 5,000 feet east of the siren is not shown, but had nearly identical test results. Between both locations there were trees covering about half the distance, while the remaining area was composed of mowed hay fields. Few leaves had yet fallen from the trees, leaving summer foliage conditions that tend to absorb, or buffer, sound.

Based upon the measured output signal level at the siren (110 dBC reading vs. 120-123 dBC rating), the propagation signal loss averaged 10 dB for each distance doubled. At the time, the average temperature was 65°F, wind 0 to 5 miles per hour, and half the area covered by trees. The sound level, however, at the data collection points was not necessarily loud enough to get attention. Based upon examination of siren locations plotted on the topographical maps, the expected coverage for each siren appears to be a circle with a radius of 10,000 feet.

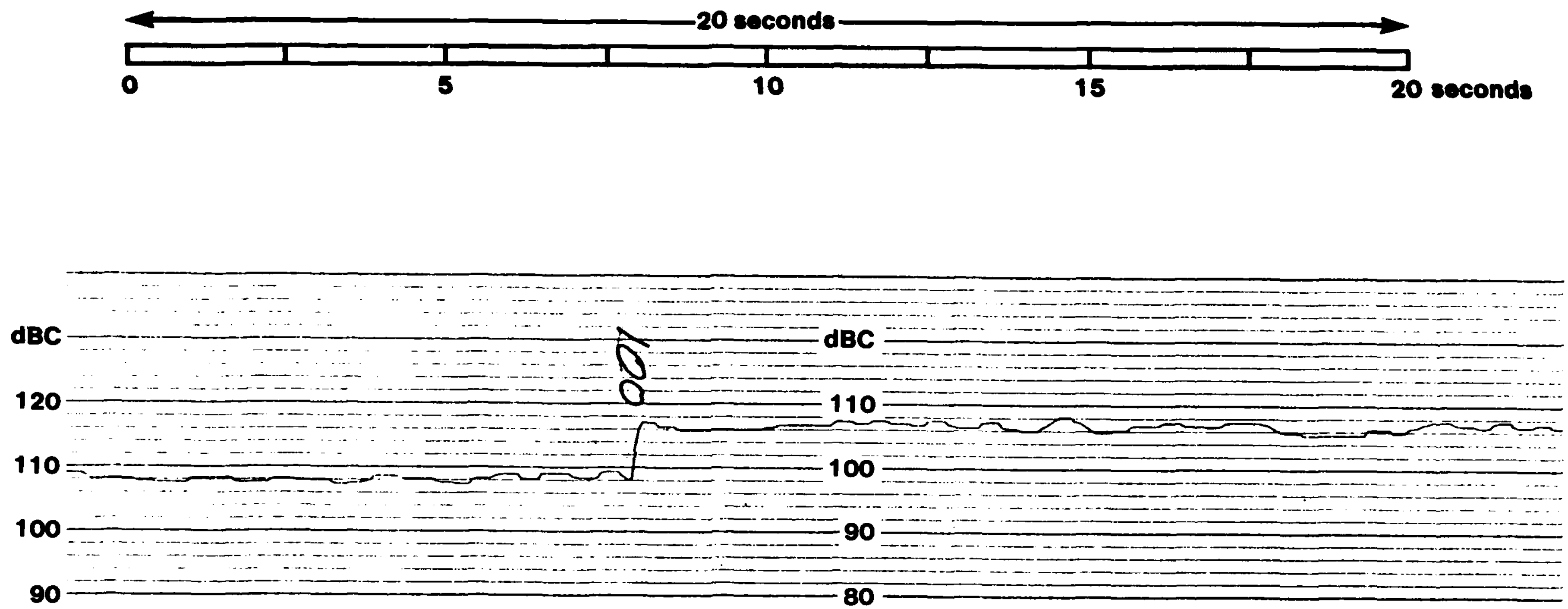


Figure A-3. North Anna Nuclear Power Plant — 120 - 123 dBC 10V2T Sentry Siren Omni-Directional Electromechanical at 100 Feet Level 50 Feet High. Sound Level Average 110 dBC.

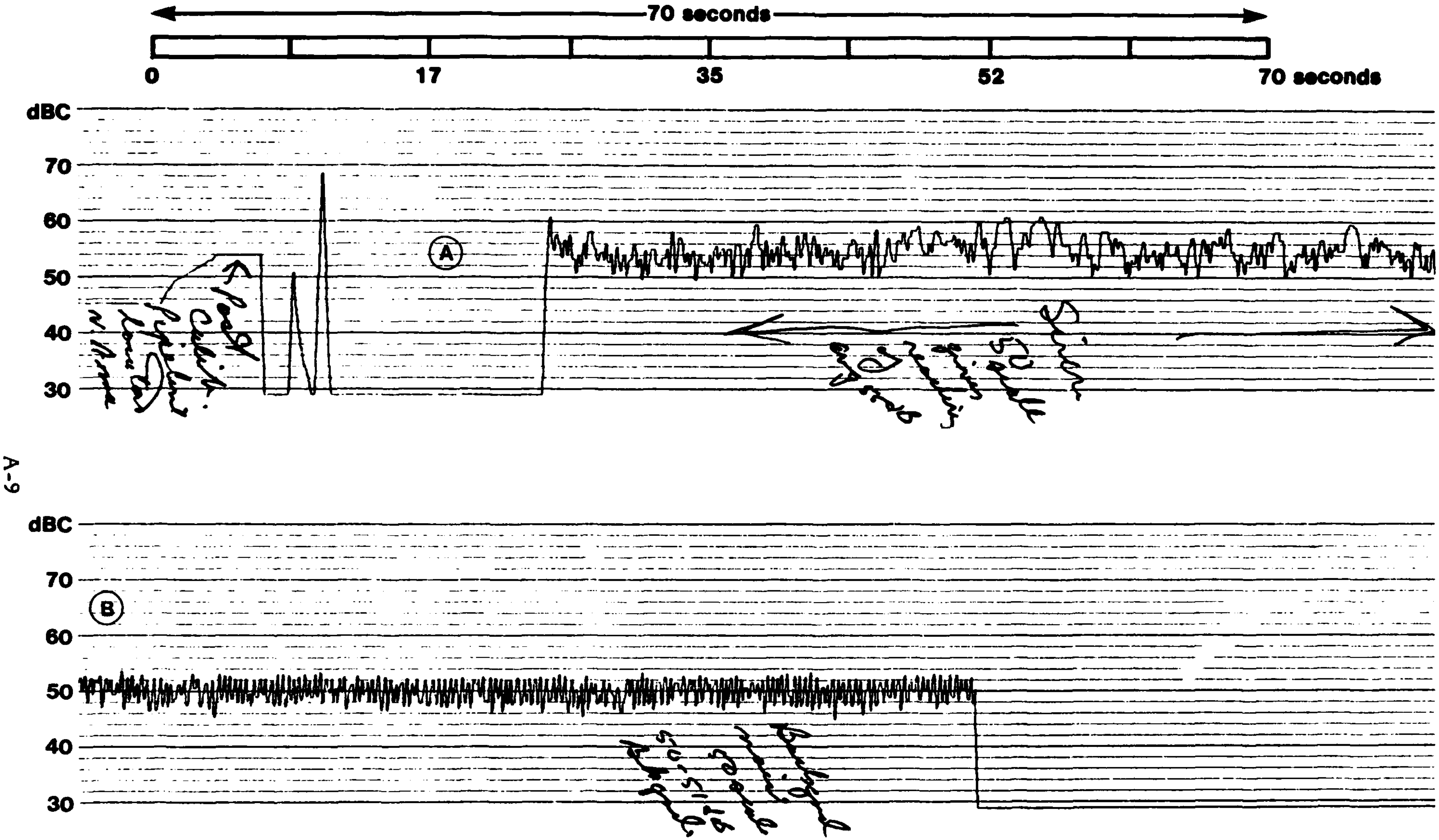


Figure A-4. North Anna Nuclear Power Plant — 120 - 123 dBC Omni-Directional 10V2T Sentry Siren - (A) Test Locat' .n 5000 Feet West of Siren; Siren Output Measured at 110 dBC. (See Figure A-3.) Received Signal Average 50 to 60 dBC. (B) Same Location Showing 48 - 52 dBC Background Noise (Compressed Time).

A-1-3 CALVERT CLIFFS SITE VISIT AND TEST

Calvert Cliffs Nuclear Power Plant is located in Calvert Cliffs, Maryland, approximately 50 miles southeast of Washington, D.C. The plant is located on the western shore of the Chesapeake Bay. The EPZ, a nominal 10-mile radius circle, includes three counties, all of which have radio control over the sirens located in their respective counties. The Patuxent River goes through the EPZ, so nearly half of the 10-mile radius is covered by water. The land area is mostly wooded rolling hills with some farmland and a few small communities.

The siren design for this plant consists of three siren types, all electromechanical, from Federal Signal Corporation. They include the Thunderbolt 125 dBC rated, rotating directional siren; the STH10, 115 dBC rated omni-directional siren, and a few small omni-directional sirens rated at 86 dBC for localized coverage. There is a total of 56 sirens, of which 41 are the Thunderbolt type, 11 are the 115 dBC omni-directional and five are the small 86 dBC sirens. The design of this system apparently assumes coverage for the 125 dBC rated siren to be approximately a 5,200-foot radius circle and a 2,000 to 2,500 radius circle for the 115 dBC rated siren.

For this test, a calibration site was selected for the STH10, 115 dBC rated omni-directional siren with two other locations 2,100 feet north and east of this siren. The latter two locations were also 5,000 feet from a 125 dBC rotating siren. These positions afforded data collection from both sirens. The northern location consisted of open fields leading up to the STH10 siren, while the eastern location was composed mostly of wooded area. Data collection showed that the 115 dBC rated STH10 siren output level measured 116 to 118 dBC at 100 feet at siren level in a bucket truck. Figure A-5 shows the measured output siren calibration test point, and Figure A-6 shows portions of the data collected at the eastern and northern sites. Notice that both positions measured the same siren (116 to 118 dBC source) signals. The northern position shows that the received signal varies from 68 to 76 dBC (open field) while the eastern position ranged from 66 to 76 dBC. These two positions, while showing similar ranges, actually differed in received

sound consistency. See the comparison area on Figure A-6 and the corresponding area below. The sound level is more consistent and not as variable when the sound is not traveling through trees. These data (north position) when viewed on an oscilloscope showed a condition where nearly a pure sinusoidal tone can be seen and heard for about 2 seconds. Apparently propagation conditions changed to cause this phenomenon, since this did not occur at the siren. In addition, the 125 dBC directional siren from 5,000 feet could be heard by the observers but did not exceed the sound power level of the closer 115 dBC siren.

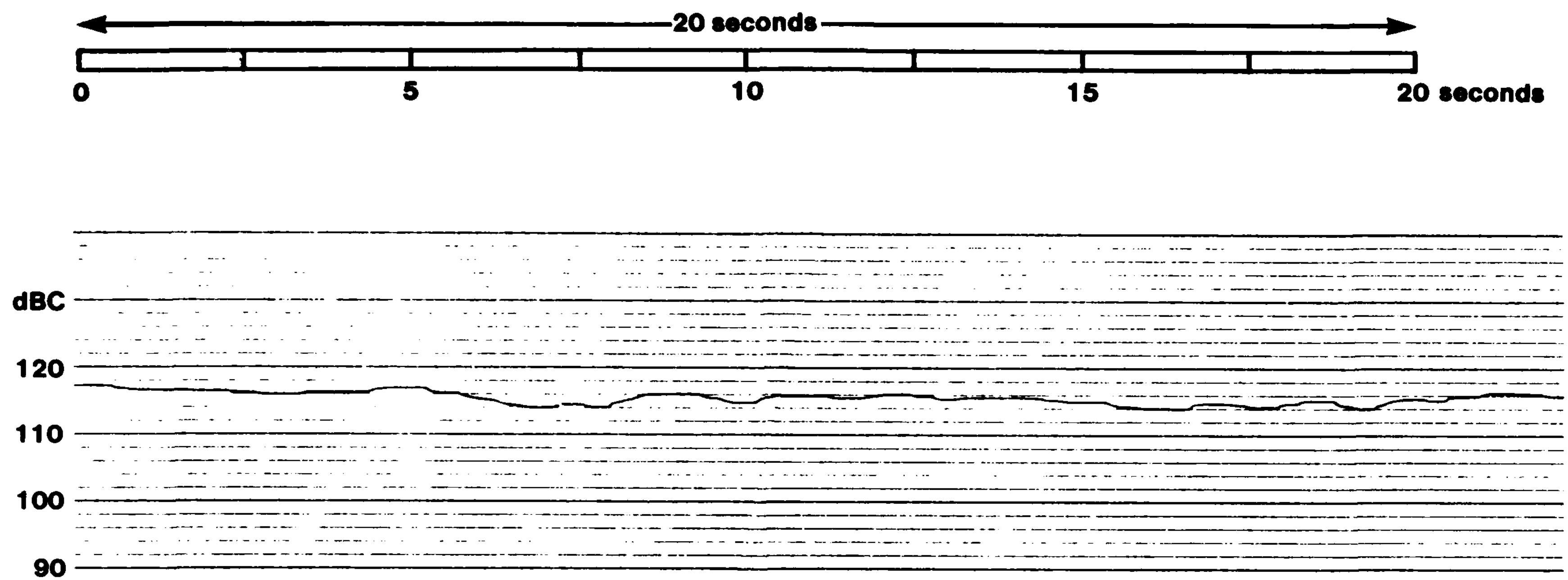


Figure A-5. Calvert Cliffs Nuclear Power Plant - 115 dBC STH 10 Federal Signal Omni-Directional Electromechanical Siren - 100 Feet at Level 50 Feet. Average 116 - 118 dBC.

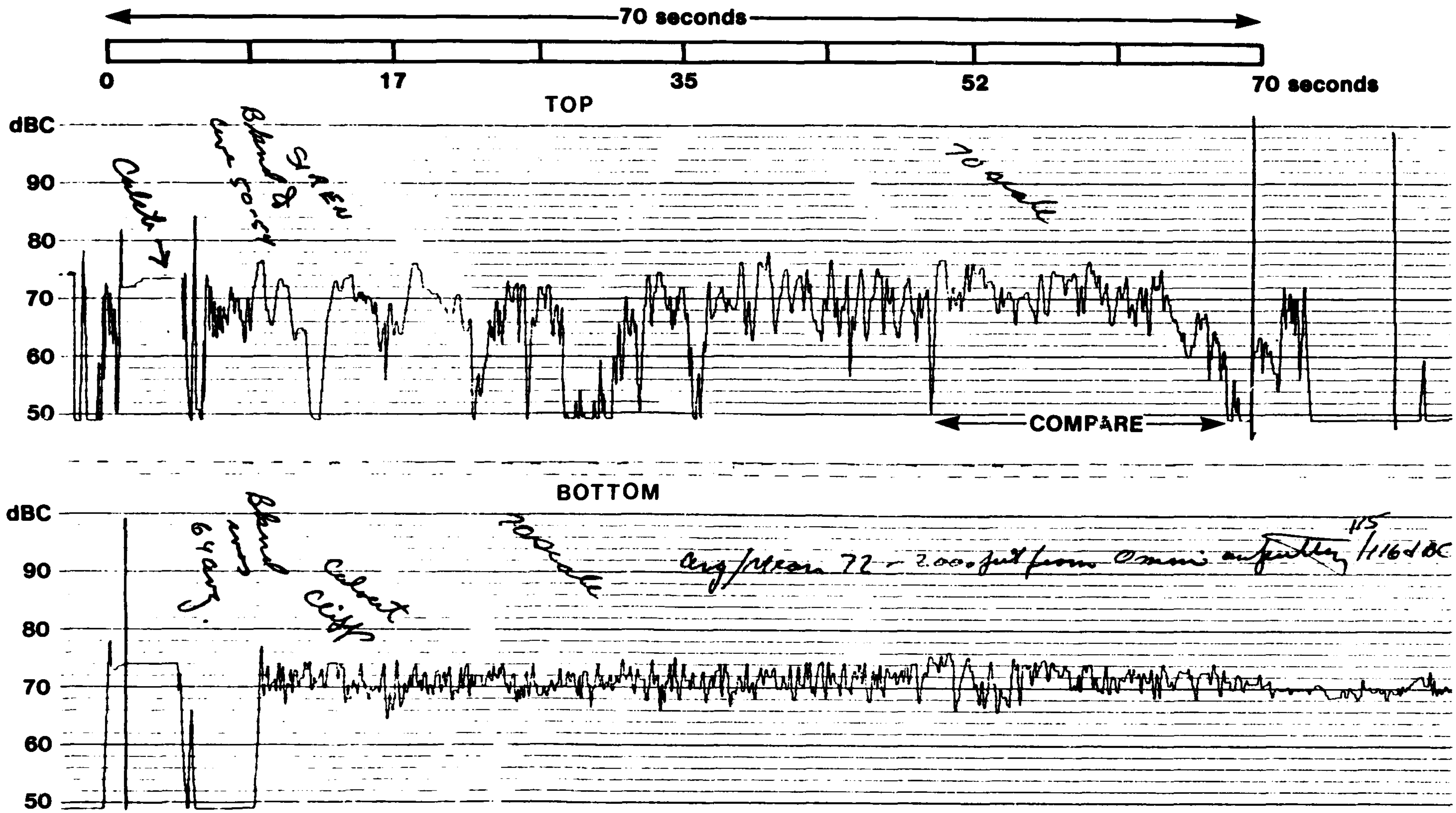


Figure A-6. Calvert Cliffs Nuclear Power Plant - Top and Bottom Areas are 2200 Feet East and North of a 115 dBC Siren (Figure A-5) Outputting 116 - 118 dBC Signal. Area Between Sirens on Top to Several Open Grass Fields; Bottom to Siren through Trees. Compared Area Shows More Sound Changes (Range) for Sound through Trees — No Open Field. Also, a 125 dBC Siren was Located 5000 Feet from Each Position but Did Not Add Significantly to Received Signal.

AD-A131 112 EMERGENCY WARNING SYSTEMS PART 2 WARNING SYSTEMS - EVALUATION GUIDELINES(U) PRC VOORHEES MCLEAN VA R C TANCZOS ET AL. JUL 83 PRC-666-PT-2 EMW-C-0680 2/2

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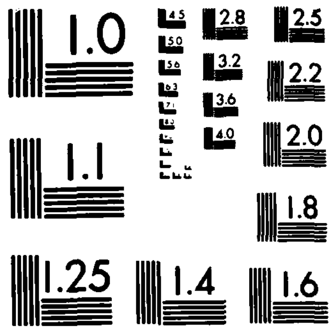

MICROCOPY RESOLUTION TEST CHART
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A-1-4 DUANE ARNOLD NUCLEAR POWER PLANT SITE VISIT AND TEST

The warning system for the Duane Arnold Nuclear Power Plant incorporated the existing weather and civil defense warning system for the City of Cedar Rapids, Iowa into a new system. The nuclear power plant located near Palo, Iowa is approximately nine miles northwest of Cedar Rapids. The existing system in Cedar Rapids contained 21 Thunderbolt 123-125 dBC rated electromechanical directional sirens. All of this system, which was installed in the late 1950s, is controlled by leased telephone lines and activated from the civil defense and police dispatch centers in Cedar Rapids.

The warning system for Duane Arnold added 27 Whelen WS3000 directional and WS2000 omni-directional electronic sirens that are radio controlled. As a result, the nominal 10-mile radius EPZ includes both the electronic sirens and the electromechanical sirens in Cedar Rapids. This EPZ includes two counties, either of which can activate the radio-controlled electronic sirens, while the Cedar Rapids electromechanical sirens are controlled over telephone lines from control centers in Cedar Rapids.

The tests conducted concerned the electronic sirens. A calibration test site was established 100 feet from a Whelen WS3000 123-124 dBC rated electronic rotating directional siren at the siren height (measured from a bucket truck). A second test site was selected 5,000 feet west of this siren and a third test site 10,000 feet west of the directional siren and 3,000 feet south of a WS2000 115 dBC rated omni-directional electronic siren. The objective of the third test site was to measure the received signal level from the WS2000 at 3,000 feet and the WS3000 at 10,000.

The actual test consisted of a one-minute steady siren tone followed by a test of the public address capability of the electronic siren. This part of the test consisted of an identification of the county activating the system followed by a count from one to five and back to one again and then a phrase stating that the test for that county was concluded. This part of the test required about 15 seconds. The next phase of the tests was conducted and controlled from a different county. The Iowa

county controlling the first test was Linn County; for the second test Benton County was used. Approximately 40 seconds of silence was then followed by a test of the wail siren signal for one minute, followed by a similar public address test. Also, during the first public address test, the directional sirens were stationary and pointed west; during the second public address test they were stationary and pointed east. Portions of the test results are shown in Figures A-7 through A-16.

Figures A-7 through A-10 show portions of the data collected at the calibration points. Figures A-11, -12, -13 show portions of the data from the same siren recorded 5,000 feet west. Mostly unharvested corn fields were between the test point and siren. Figures A-14, -15, and -16 show data from the calibration siren at 10,000 feet west as well as data from a WS2000, 115 dBC rated omni-directional siren at a distance of 3,000 feet south. There were mostly wooded areas between the WS2000 and the test point (3,000 feet) with open fields and corn fields to the calibration point.

Observe that Figure A-7 shows a portion of the WS3000 siren (rated 123-124 dBC) during the steady tone test at the calibration point. The maximum recorded signal was nominally 112 dBC when pointed directly at the recording instruments. Figure A-8 shows the conclusion of this steady tone test when the siren rotated and then stopped, pointing directly at the test instruments. Notice the 112 dBC signal followed by a recording of this voice test. The test words were as follows, "Linn County testing, one, two, three, four, five, five, four, three, two, one. End of test, Linn Sheriff." The maximum voice output level measures 96 dBC ranging from less than 80 dBC to 96 dBC. The data from Figure A-7 can now be compared to those of Figures A-11 and A-14.

Figure A-11 shows that data at 5,000 feet indicate a received siren signal maximum of 71-73 dBC when the siren was pointed at this data collection site. This can be compared to a signal loss average less than 8 dBC per distance doubled. This is much better than is normally expected. Also, compare Figure A-8 calibration voice test data to Figure A-12 for voice test recordings at 5,000 feet. Here the voice levels range from 55 to 65 dBC compared to calibration source

voice recording from 80 to 97 dBC. This would seem to show even less than 8 dBC attenuation. The same data shown in Figure A-15 shows identical voice recordings with maximum levels near 60 dBC at a distance of up to 10,000 feet. The data point was also 3,000 feet from an omni-directional siren. However, the directional siren at 10,000 feet was actually clearer, louder, and more easily understood than the closer omni-directional siren. Note that the siren at 10,000 feet was pointed directly at the test station. The other figures show the results of the wail test (compare Figure A-9 with A-13 and A-16). The maximum recorded output signal during the wail test was 119 dBC and is much closer to the rated siren output. Notice in Figure A-10 at the calibration point, the maximum and minimum recorded signal level for when the directional siren is pointed toward and away from the data collection test points. At the end of the wail test, the directional siren was pointed east and directly away from the other two data collection points. During this time a voice test using public address capability was again made. The test points could not record the voice signals above background noise and the message could not be understood.

In comparing these tests to others, the factor of most importance is that the siren signal loss averaged 8 dBC per distance doubled as compared to 10 dBC for most other tests. This is probably attributed to the fact that the electronic siren frequencies were lower than others (averaging less than 500 Hertz), and would have less attenuation in this environment, and also, by the fact that the land was fairly flat and few trees were in line with the 5,000- and 10,000-foot test stations.

Secondly, the public address voice tests had excellent propagation effects (losses less than 8 dBC per distance doubled), and the message could be easily understood at a distance nearly two miles (10,000 feet) from the source. Test conditions included the temperature at 66°F at test time with winds 0-10 mph, most leaves remaining on trees, and corn fields unharvested.

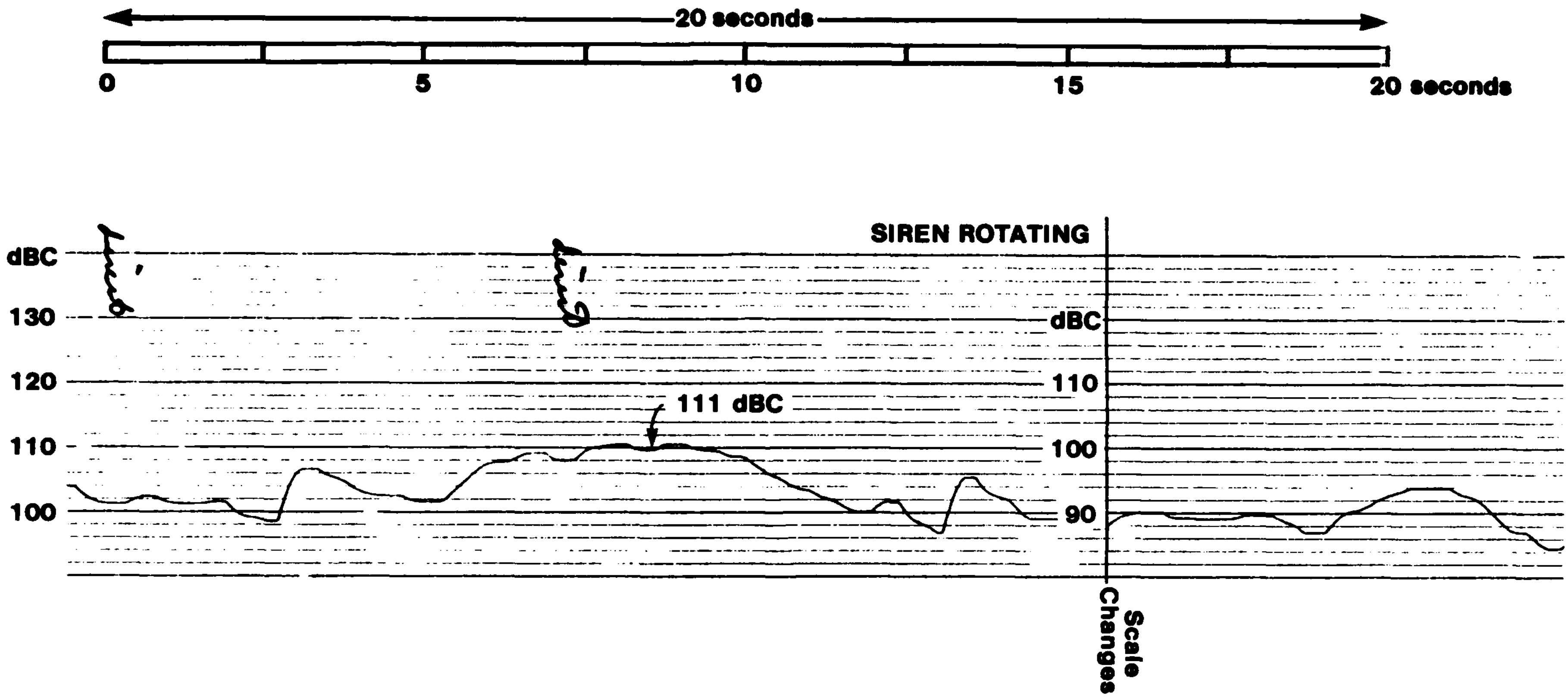


Figure A-7. Duane Arnold Nuclear Power Plant - 124 dBC Whalen WS3000 Directional Electronic Siren at 100 Feet Level to Siren - Approximately 50 Feet High. Maximum Reading During Steady Tone 112 dBC.

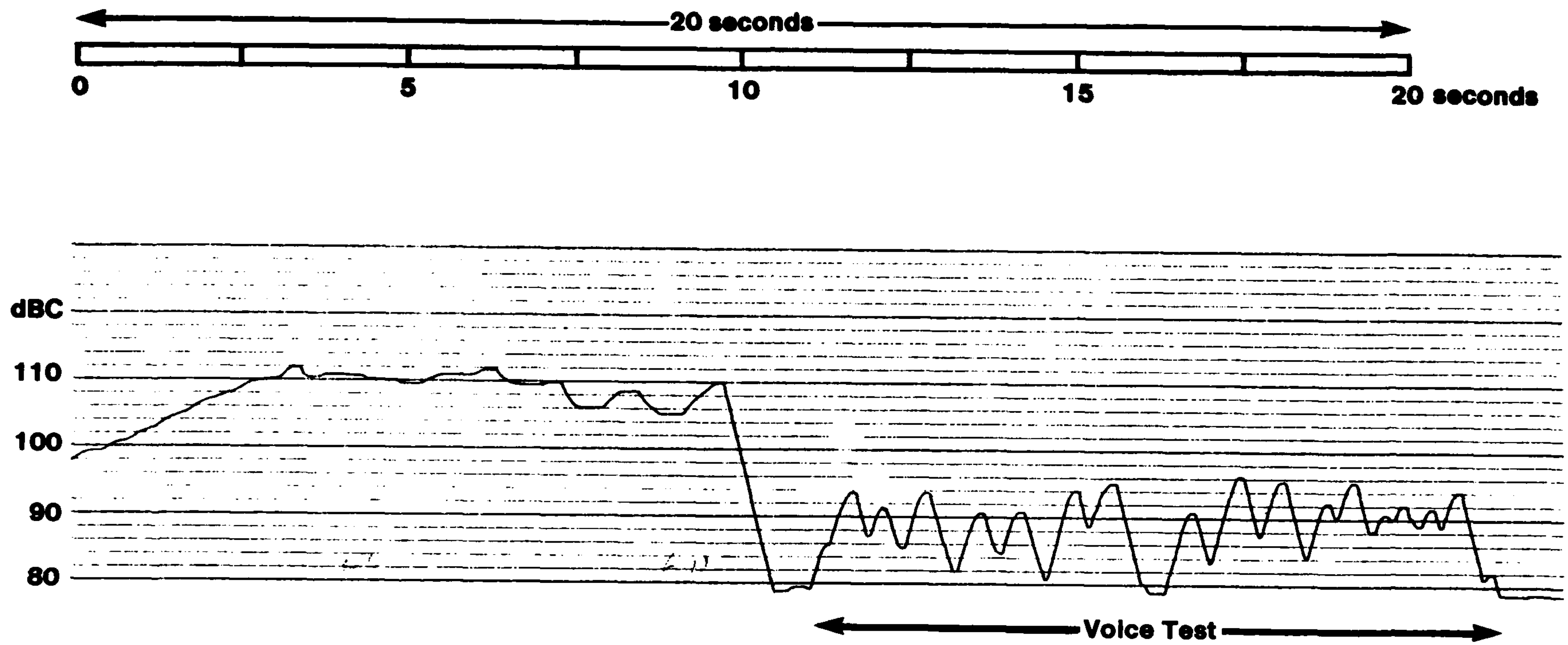


Figure A-8. Duane Arnold Nuclear Power Plant - 124 dBC Whalen WS3000 Directional Electronic Siren at 100 Feet Level to Siren - Approximately 50 Feet High - Voice Test.

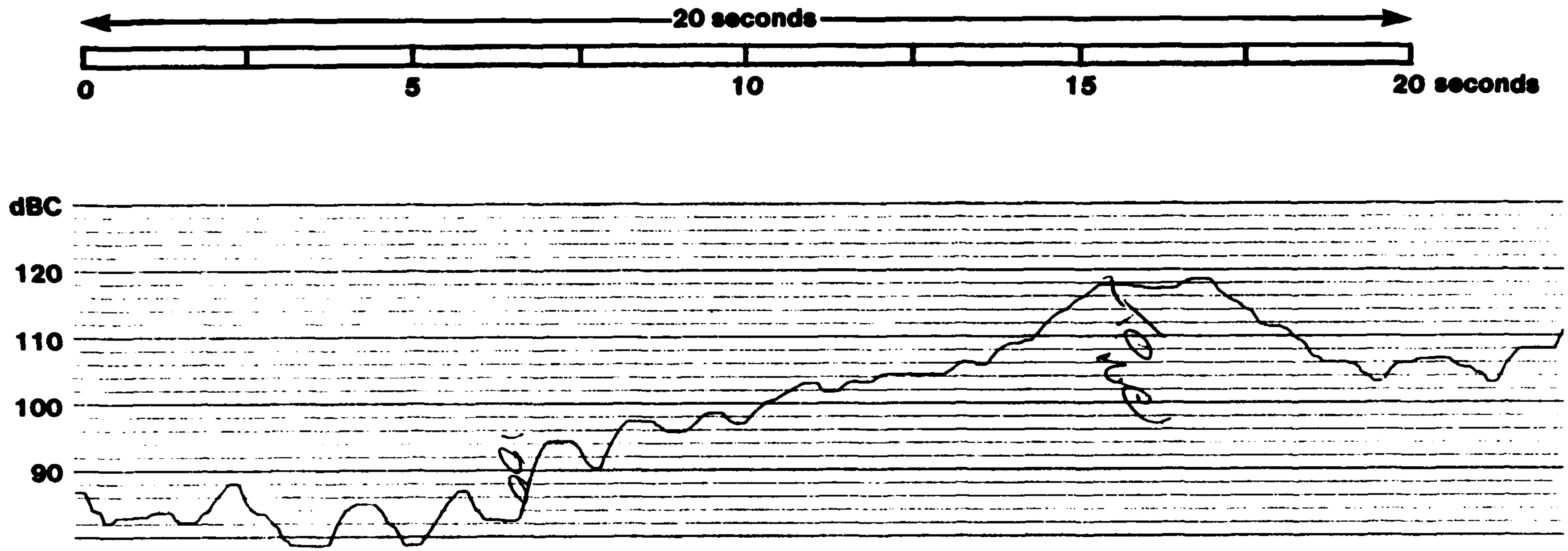


Figure A-9. Duane Arnold Nuclear Power Plant - 124 dBC Whalen WS3000 Directional Electronic Siren at 100 Feet Level to Siren - Approximately 50 Feet High - Maximum Reading During Wail Test 119 dBC.

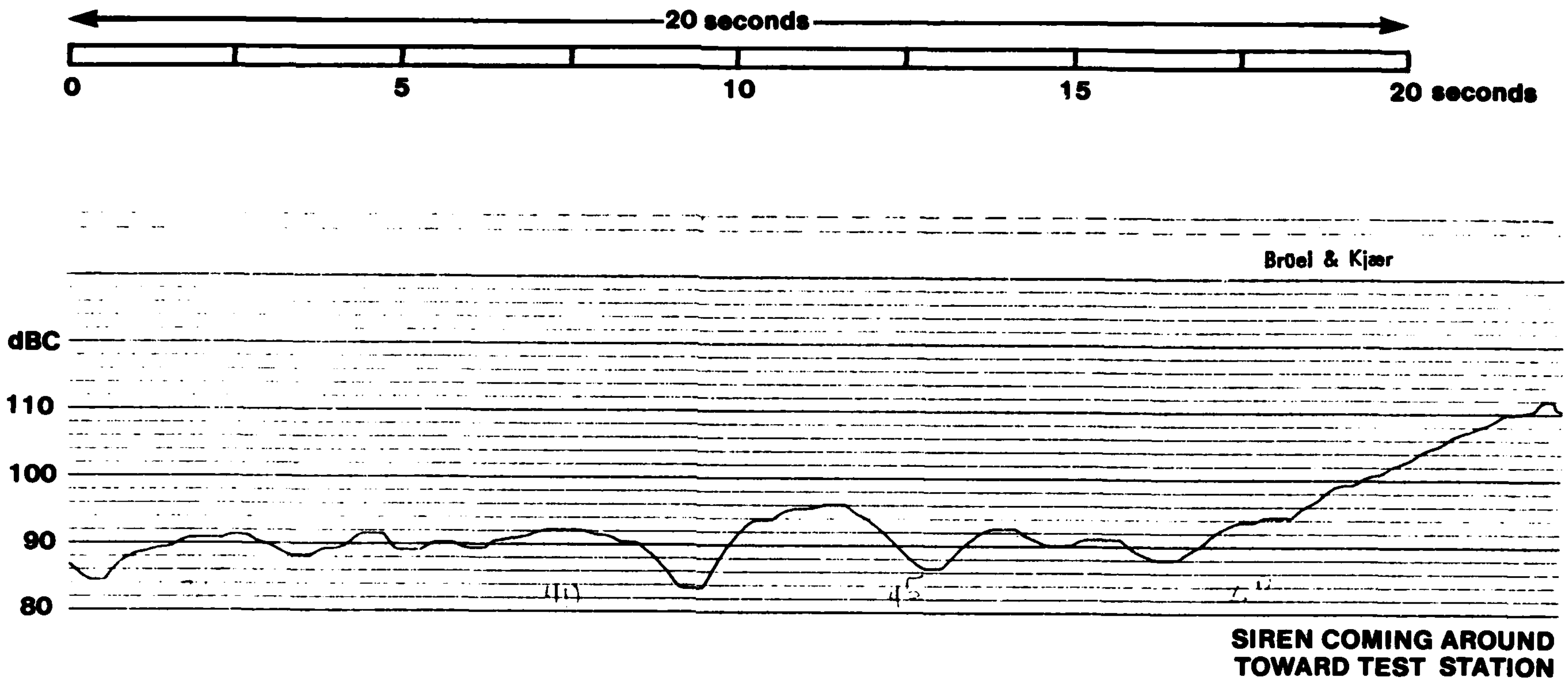


Figure A-10. Duane Arnold Nuclear Power Plant - 124 dBC Whelen WS3000 Directional Electronic Siren at 100 Feet Level to Siren at 50 Feet High - Siren Level (Steady Tone) when Pointed Away - Varies from 85 - 95 dBC. Difference is Over 22 dBC Between Pointing Toward and Away from Test Station.

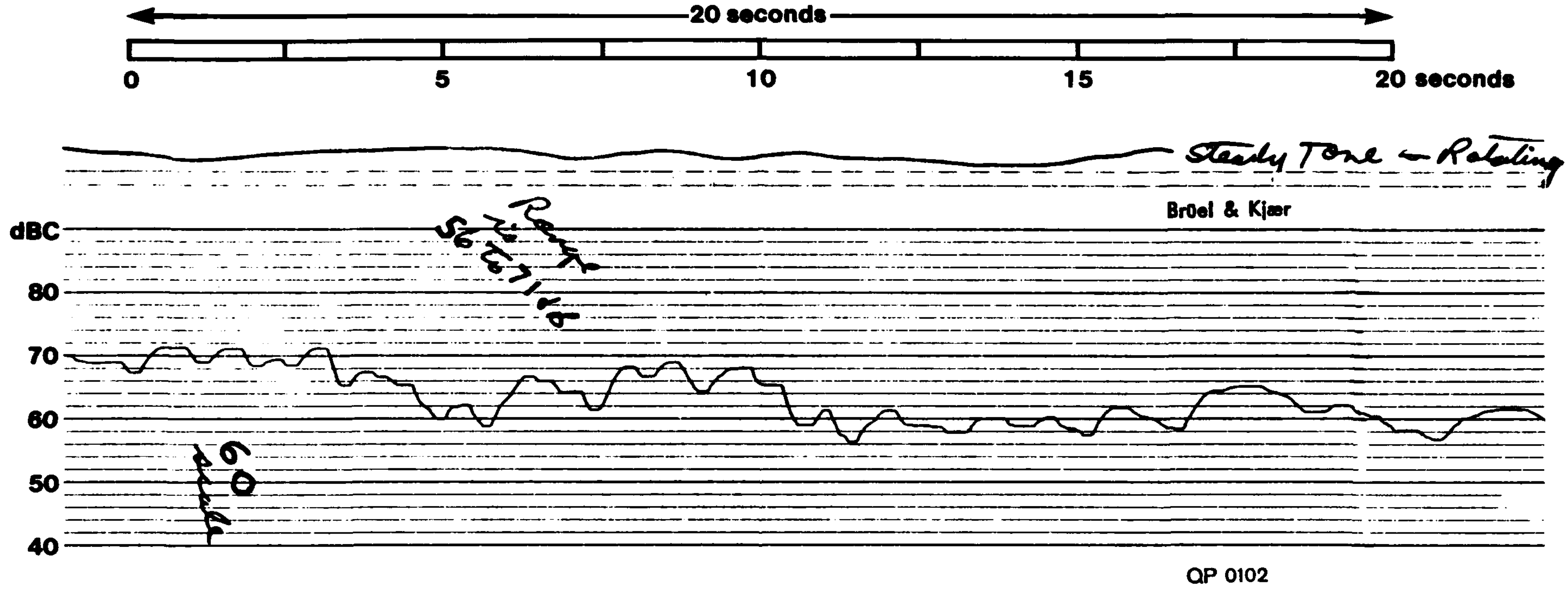


Figure A-11. Duane Arnold Nuclear Power Plant - Position 5000 Feet from 123 dBC Rotating Directional (Figures A-7 through A-10) Outputing 112 dBC (Figure A-7). Recorded 73 dBC Maximum with Siren Pointed at Test Point.

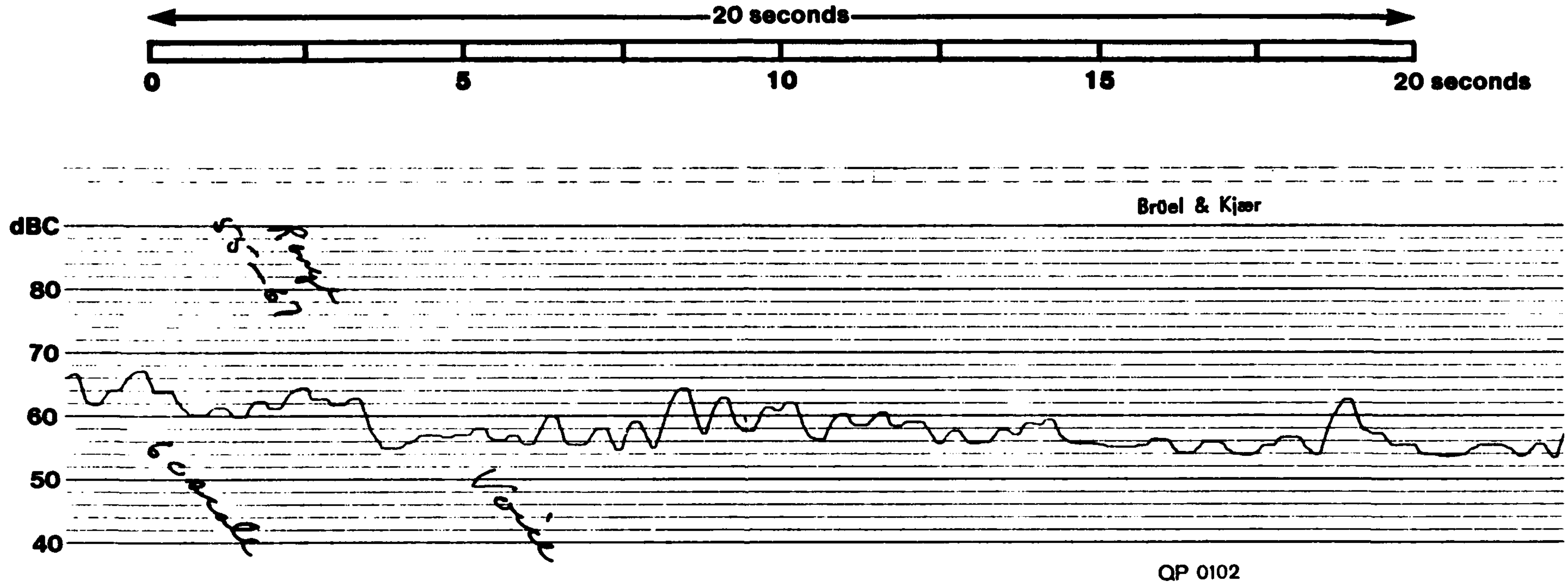


Figure A-12. Duane Arnold Nuclear Power Plant -5000 feet from Source, Voice Test of Electronic Siren WS3000 Pointed Directly at this Test Station. Voice Signal Varies from 55 to 66 dBC. Source Varies from 80 to 96 dBC (Figure A-8 Is Source).

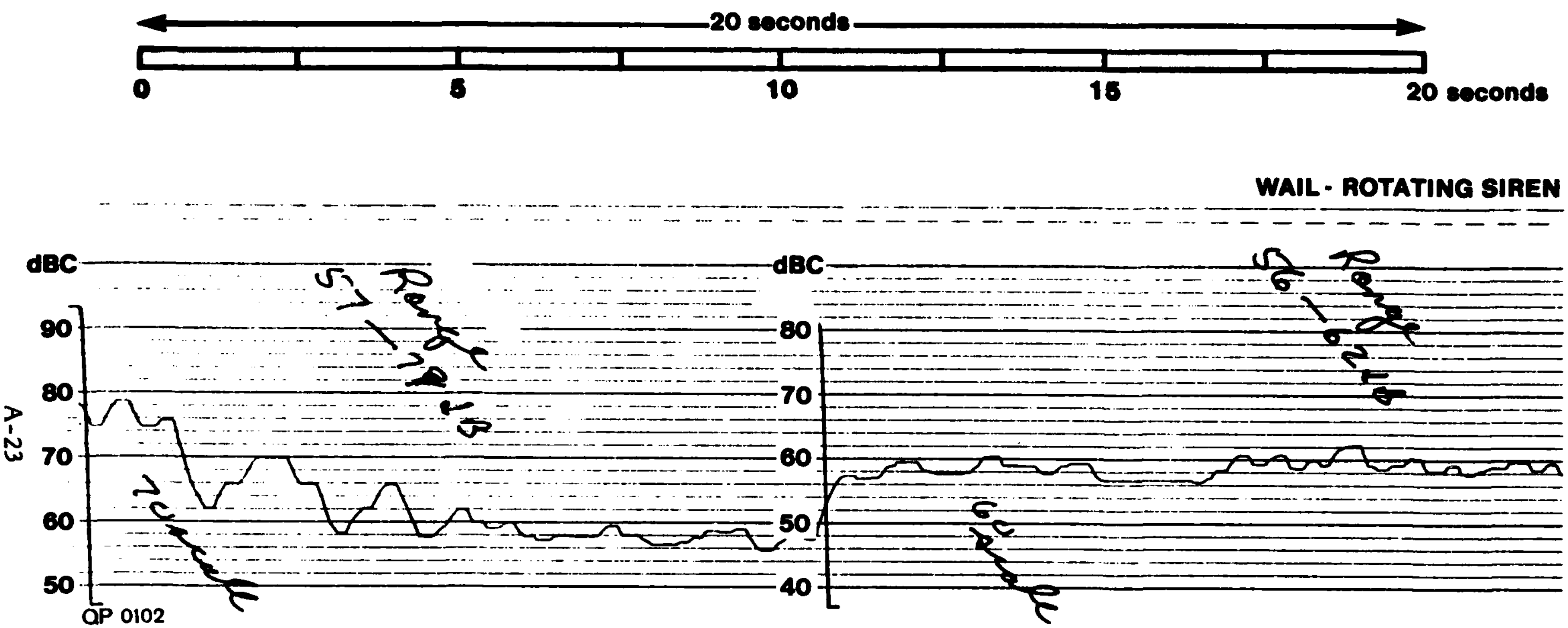


Figure A-13. Duane Arnold Nuclear Power Plant 5000 Feet from Source (Figure A-9) Maximum Signal 79 dBC when Pointed at Test Position. Source Maximum 119 dBC.

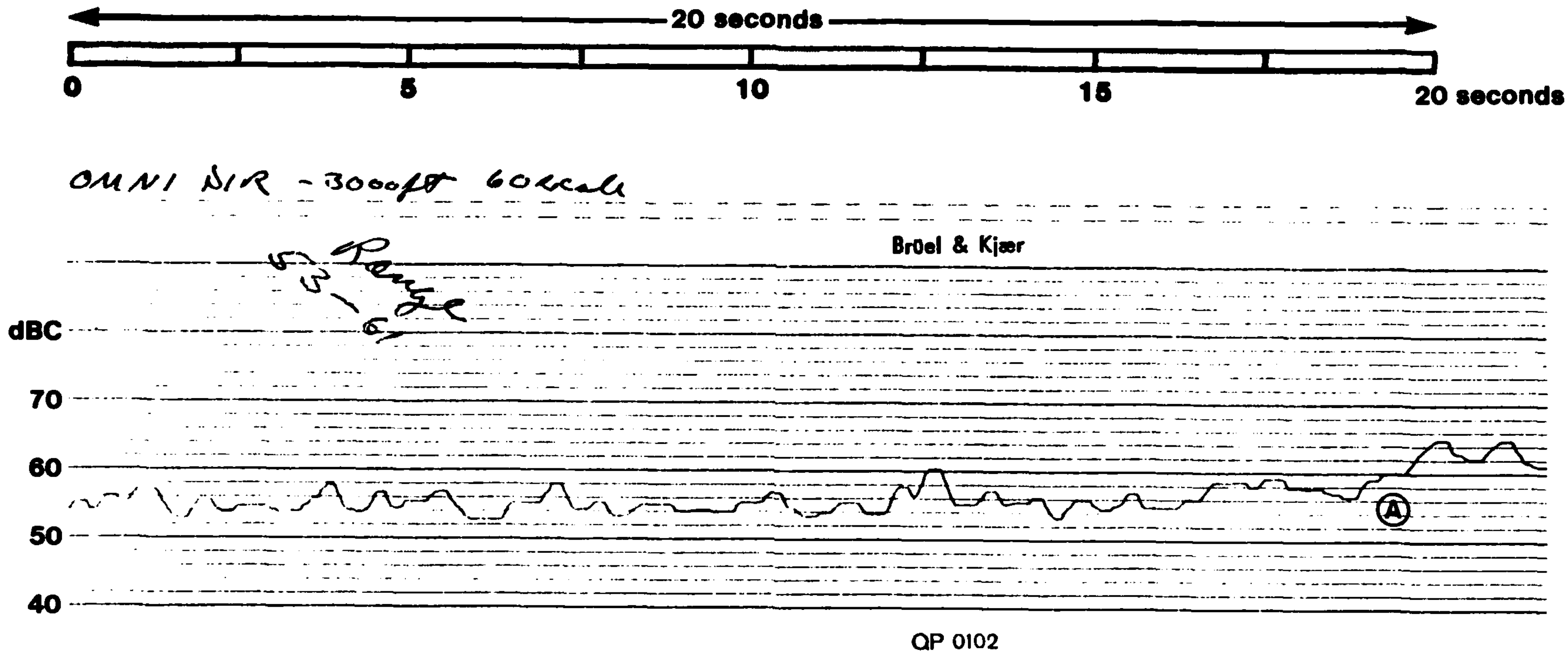


Figure A-14. Duane Arnold Nuclear Power Plant - 3000 Feet from WS2000 (115 dBC Omni-Directional) and 10,000 Feet from WS3000 (Directional) Electronic Sirens. Directional Siren Steady Tone Averages 53 - 61 dBC. At Time A, Directional Siren (Source A-7) Overrides Omni-Directional, Giving 65 dBC at 10,000 Feet.

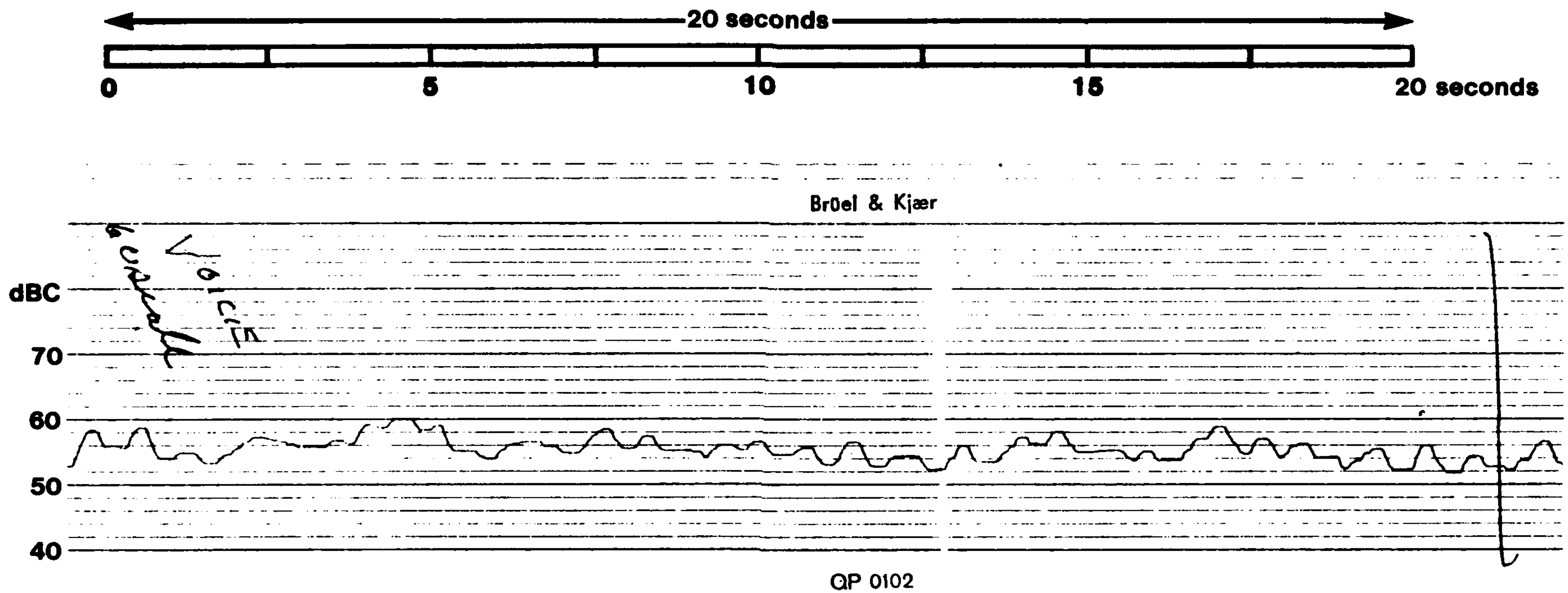


Figure A-15. Duane Arnold Nuclear Power Plant - Voice Test of Electronic Siren - 3000 feet from WS2000 and 10,000 Feet from WS3000, which is Directed at this Test Station. Voice Ranges from 54-60dBC. Voice from Directional Siren at 10,000 Feet (Figure A-8) Predominate over that from Siren at 3000 Feet.

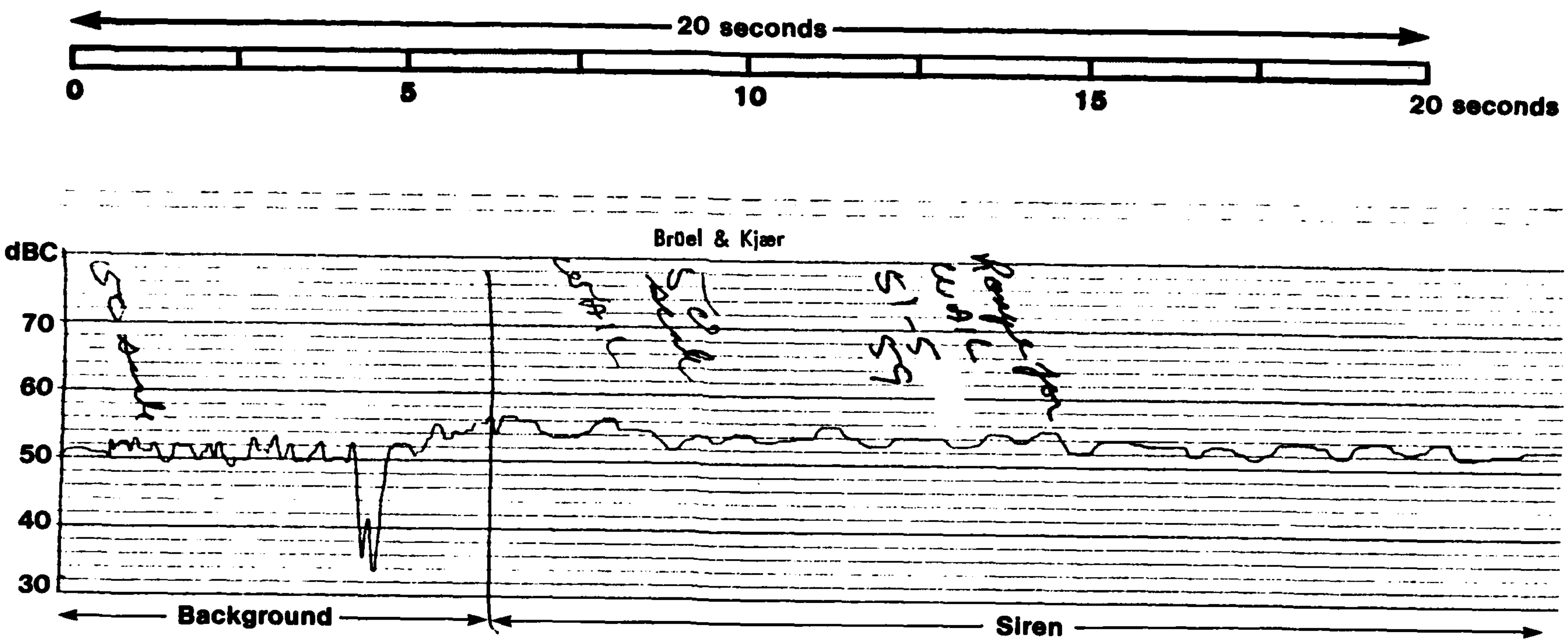


Figure A-16. Duane Arnold Nuclear Power Plant - 115 dBC WS2000 Whelen Electronic Omni-Directional Siren - 3000 Feet from Siren — Wall Test Average 54 dBC - Range Measured from 51 - 59 dBC. Background Average 51 dBC.

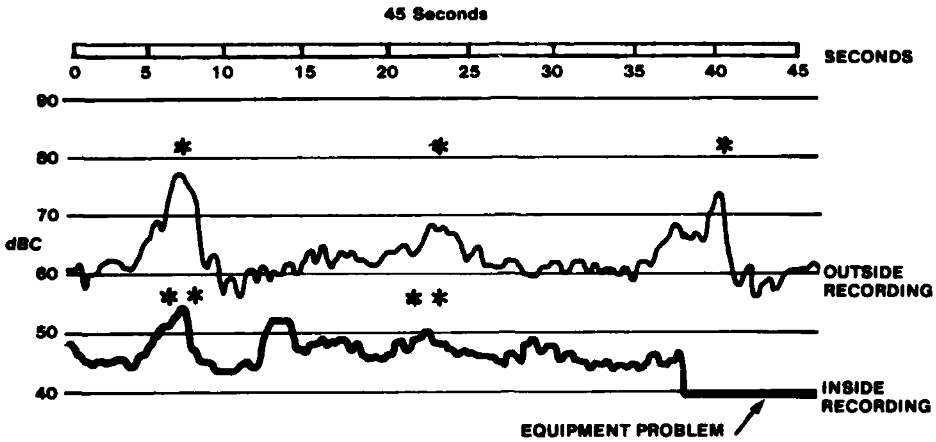
A-1-5 WAWAS OUTSIDE/INSIDE TESTS

Three separate tests were conducted to collect data on background noise inside typical houses and to measure sound signal transmission losses from outside to inside of these houses. The WAWAS system is tested monthly on every second Wednesday at 11:00 a.m. for one and one-half minutes. Three houses in the WAWAS area were selected as test sites.

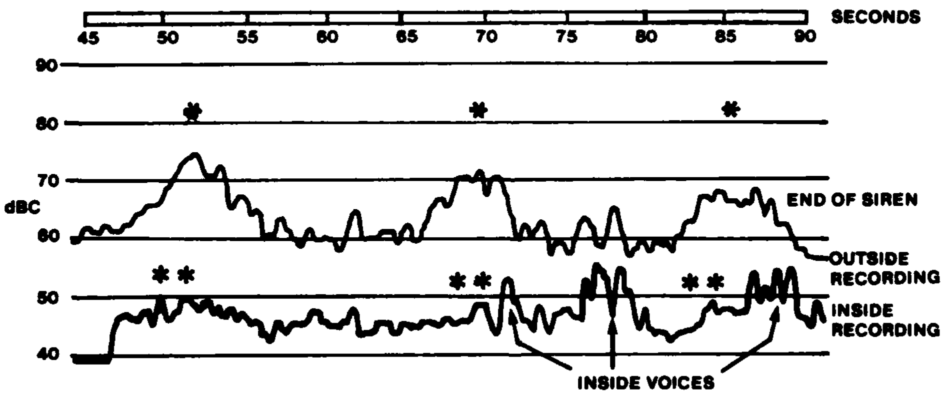
The first test was conducted at a house in Alexandria, Virginia, which was located 2,400 feet from an Allertor 123-125 dBC rated rotating directional electro-mechanical siren. The area was suburban, with single-family houses. One test station outside the house and one inside, were selected. The siren signal was not loud enough to exceed the background noise level and was not audible inside the house. It was expected to be in the 75-85 dBC range but was actually below the background noise level of 50-60 dBC. It could not be determined what the exact output level was of the siren; however, since it was not reported to have failed. One assumption may be that the siren was not operating at its maximum rated output power level.

A second WAWAS test was conducted in Aspen Hill, Maryland outside and inside a wood-frame split-level house constructed around 1966. A Thunderbolt 123-125 dBC rated electromechanical directional siren was located 1,500 feet away, and slightly uphill. The area was a suburban area of single-family houses. The test results are shown in Figure A-17. Notice that the siren sound transmission loss from outside to inside ranged from 21-26 dB. The maximum signal recorded outside was 77 dBC. During the test when the house was quiet, the outside to inside sound differential was generally 12 to 25 dB. However, with typical conversation in an open room adjoining the test area, the differential between background and siren level is less than 10 dB when voices are heard.

A third outside to inside test was performed in Falls Church, Virginia. The sirens, although located 1,300 feet from a brick house, did not function for the test. Therefore, only typical background noise readings were taken.



* Redrawn for Clarity



*** Maximum Outside Siren Signal Level**

*** * Maximum Inside Siren Signal Level**

Sound propagation loss outside to inside ranges from 21 - 26 dB differential. Readings from split level home, 15 years old with inside meter 10 feet from large window in line to siren. Maximum outside siren signal 77 dBC. Maximum inside siren signal 55. Doors and windows closed, temperature 54°F, wind 0-6 mph. Siren 1500 feet from home (ACA Allerton).

Figure A-17. WAWAS - Aspen Hill, Maryland

A-1-6 MAINE YANKEE SITE VISIT AND TEST

The Maine Yankee Nuclear Power Plant is located about eight miles east northeast of Bath, Maine. This area is near the Maine coast and has many harbors, rivers, and inlets that comprise about 35 percent of the 10-mile radius EPA. Nine omnidirectional ACA-rated electromechancial sirens are placed within the EPZ. They are radio activated. This system makes external use of mobile sirens throughout the area. In addition, a few sirens that are part of the volunteer fire departments were used during the test. Unfortunately, the siren selected for data collection did not function for this test. However, a local fire siren did operate and data from this siren and several mobile sirens were recorded. These data are shown in Figures A-18 and A-19. Three data collection sites were selected. However, only data from one of three sites are used, here since one site had an equipment malfunction and the other had data similar to that shown in the figures.

The temperature during this test was between 29° to 33° F with a slight breeze and three inches of snow on the ground. Figures A-18 and A-19 recorded the data using both the A and C scales. For siren signals, the dBC scale shows signals averaging 5 to 12 dB higher than those recorded on the A scale. Figure A-19 shows a mobile siren approaching the test point.

In summary, the mobile sirens, which operated for nearly 45 minutes of the test, were very noticeable from the fact that they operated much longer than would otherwise be normal for emergency vehicle sirens. No public address features were used on these units. Also, a malfunction eliminated 5 of the 9 fixed sirens from operation, thereby making the function of the mobile units more important.

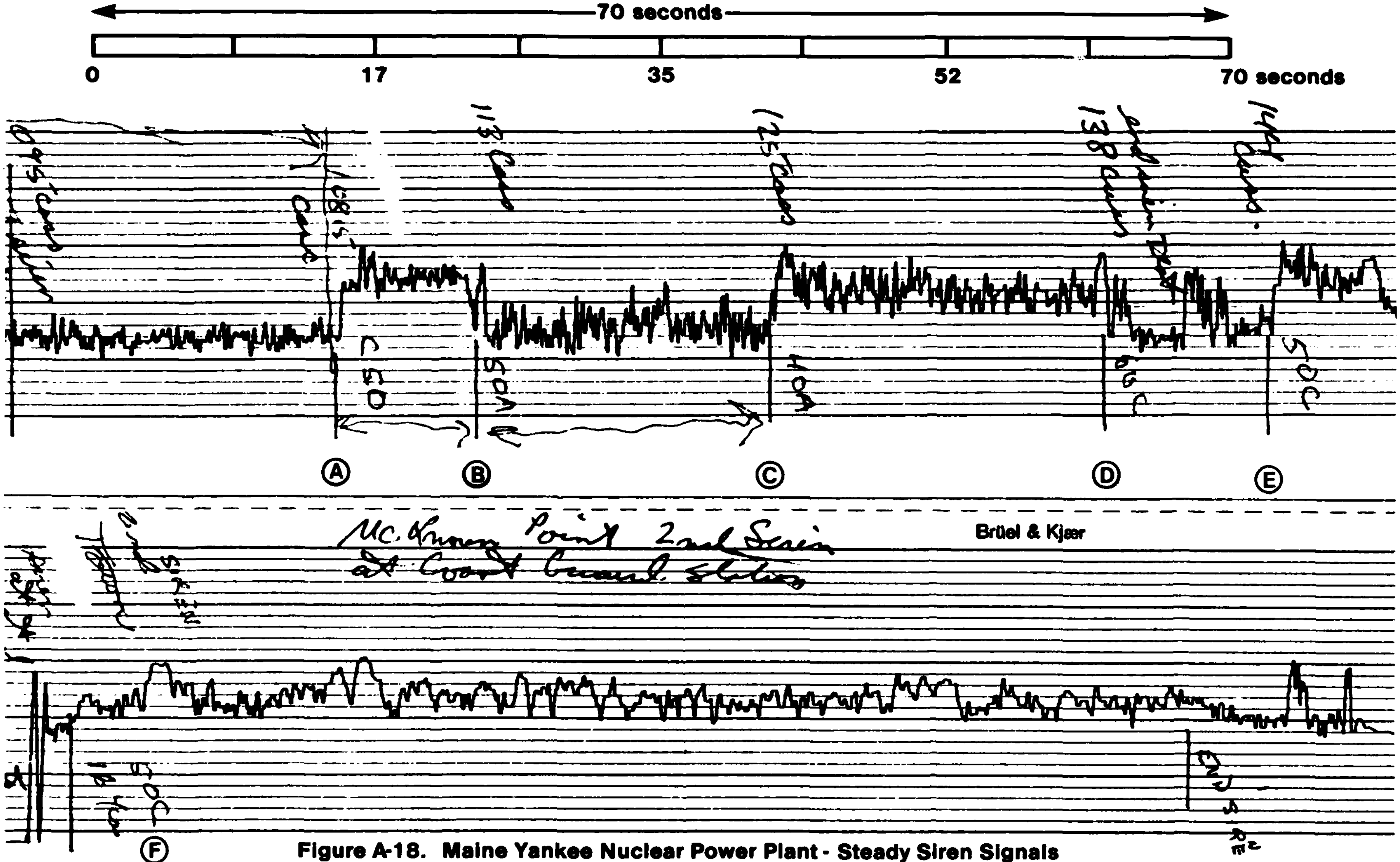


Figure A-18. Maine Yankee Nuclear Power Plant - Steady Siren Signals Measured Using dBA and dBC Scales. Top Graph (A) shows Measurement on dBC 50 Scale (Reading Average 55dBC); (B) dBA 50 Scale (Average 45 dBA; (C) dBA 40 Scale (Average 43 dBA; (D) dBC 60 Scale (Average 54 - 62 dBC); (E) dBC 50 Scale (Average 48 - 60 dBC); (F) dBC 50 Scale (Average 50 - 60 dBC). (Exact Siren Position Unknown.)

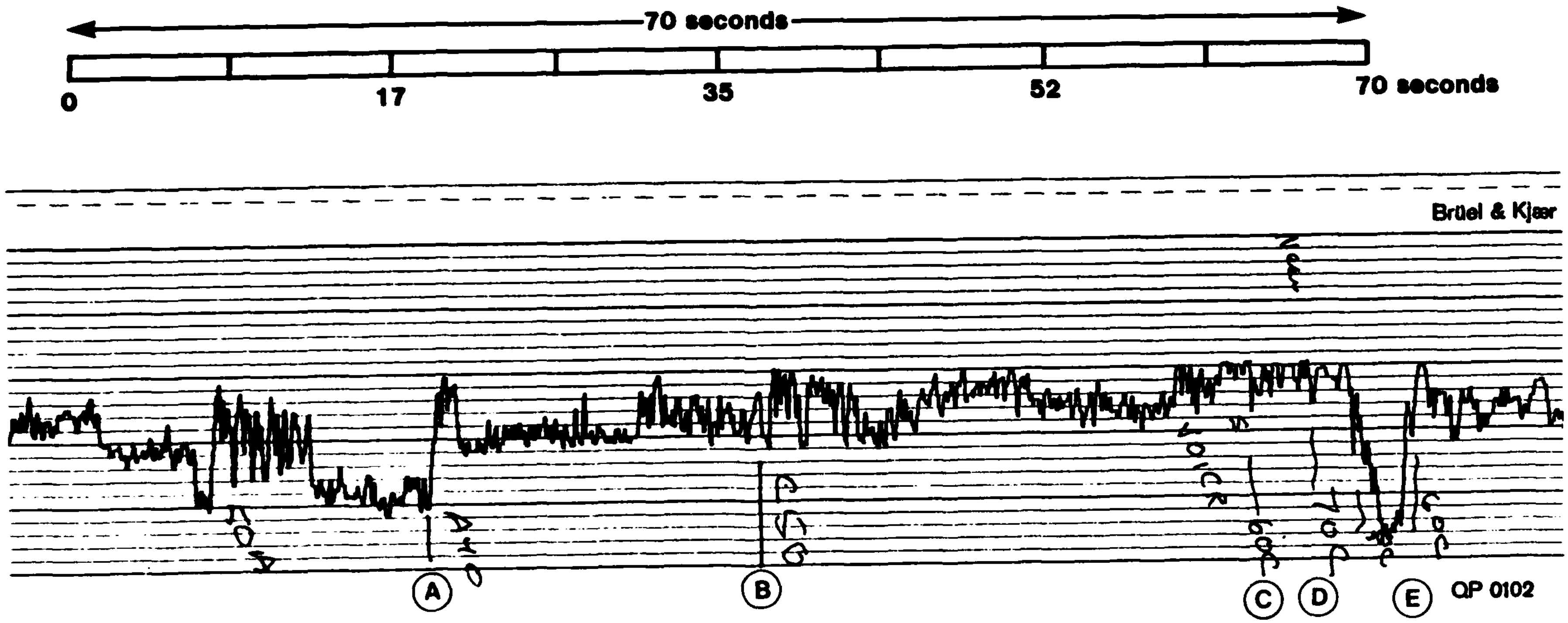


Figure A-19. Maine Yankee Nuclear Power Plant - Mobile Siren Measured on dBA and dBC Scales. (A) Mobile Siren at a Distance dBA 40 Scale (Average 41 dBA); (B) dBC 50 Scale (Average 54 - 56 dBC); (C) Mobile Unit 400 - 600 Feet dBC 60 scale (Average 68 dBC); (D) Mobile Unit 200 - 300 Feet dBC 70 Scale (Average 78 - 80 dBC); (E) Mobile Unit Leaving dBC 60 Scale - Range from 66 dBC to 58 dBC.

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APPENDIX C. INDEX

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